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Eleven descriptive studies prepared by independent experts and dealing with the employment impact of technological change are presented. Part I contains (1) an analysis, at the establishment level, of employment-increasing growth of output and employment-decreasing growth of output per man-hour, (2) case studies of the elapsed time involved in the process of invention, innovation, and diffusion of selected new technologies, and (3) a review of literature, on this same subject by Edwin Mansfield. Part II deals with the employment impact of technological developments occuring in agriculture, banking, and steel-making and includes an evaluation and speculations for the future in three papers. Part III treats the impact upon skill requirements in selected automatic installations, examines the same problem by looking at the raw data upon which the 1949 and 1960 editions of the "Dictionary of Occupational Titles" were based, and examines changes occurring in the nature of work. Part IV examines current issues related to shortening the basic workweek and compares the possibilities for growth in income or leisure in an economy where the output of an hour's work doubles in less than a quarter century. Other appendixes to VT 003 962 are VT 003 960 and VT 005 794-VT 005 797. (EM)

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THE EMPLOYMENT IMPACT OF TECHNOLOGICAL CHANGE

Appendix Volume II

TECHNOLOGY AND THE AMERICAN ECONOMY, The Report of the Commission

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and Economic Progress • February 1966

THE
EMPLOYMENT IMPACT OF TECHNOLOGICAL CHANGE

Appendix Volume II

TECHNOLOGY AND THE AMERICAN ECONOMY,

The Report of the Commission

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PREFACE

This volume is the second of six appendix volumes to Technology and the American Economy, the report of the National Commission on Technology, Automation, and Economic Progress. The full series of appendix volumes is as follows:

I. The Outlook for Technological Change and Employment
II. The Employment Impact of Technological Change
III. Adjusting to Change
IV. Educational Implications of Technological Change
V. Applying Technology to Unmet Needs
VI. Statements Relating to the Impact of Technological Change.

This volume contains 11 studies dealing with the employment impact of technological change, prepared by independent experts at the request of the Commission.

Part 1 deals with the pace of technological change, and contains three studies, the first by the Bureau of Labor Statistics. The BLS has for several years contributed significantly to understanding the employment impacts of technological change through its "disemployment" analysis—comparison for the economy and for industry sectors of the net relationship between employment-increasing growth of output and employment-decreasing growth of output per man-hour. At the request of the Commission, BLS extended that analysis to the establishment level, finding little difference in general between industry relationships and establishment relationships. Frank Lynn undertook a number of case studies of the elapsed time involved in the process of invention, innovation, and diffusion of new technologies, and Edwin Mansfield undertook a review of the literature on the subject. Both concluded that some acceleration in the pace had apparently occurred but that the time involved was sufficiently long to support Lynn's judgment that "any technology which will have a significant impact upon employment and unemployment within the next 10 years must already be in a readily identifiable stage of commercial development."

Part 2 deals with the employment impact of technological change by industry. Butcher, Newhouse, and Haller each describe technological developments occurring in agriculture, banking, and steelmaking, respectively, evaluate the employment impact of those technologies, and speculate upon the future.

Part 3, on skill requirements, contains three studies. James Bright, through a series of case studies, examines the impact upon skill requirements of a number of actual installations of automatic equipment. He finds that the general tendency is to reduce rather than to increase the skill content of the jobs. Horowitz and Herrnstadt approach the same problem by examining the raw data upon which the 1949 and 1960 editions of the *Dictionary of Occupational Titles* were based. They found no significant changes in skill requirements in general over the period. Charles Walker, also through case studies, does find significant changes occurring in the *nature* of work.

In part 4, on hours of work and leisure, Myron Joseph examines current issues related to shortening the basic workweek and comes to negative conclusions. Kreps and Spengler compare the alternative possibilities for growth in income or leisure in an economy where the output of an hour's work doubles in less than a quarter century.

Additional studies prepared for the Commission are contained in Appendix Volumes I, III, IV, and V. Appendix Volume VI contains a group of statements by various interested organizations and individuals in response to a request from the Commission for their views on the impact of technological change.

Though the Commission does not necessarily endorse the information and views of these documents, it considers them of sufficient value to have directed their publication.

This volume was edited and prepared for publication by Judith Huxley.

GARTH L. MANGUM,
Executive Secretary.

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I. The Outlook for Technological Change
III. Adjusting to Change
IV. Educational Implications of Technological Change
V. Applying Technology to Unmet Needs
VI. Statements Relating to the Impact of Technological Change

Part 1

PACE OF TECHNOLOGICAL CHANGE

DISEMPLOYMENT OF LABOR AT THE ESTABLISHMENT LEVEL

Prepared for the Commission

by the

Bureau of Labor Statistics

U.S. Department of Labor

PREFACE

This report presents the findings of a study on the declines of establishment employment (or aggregate man-hours) associated with productivity increases and with output decreases. The declines in employment associated with productivity increases have been termed "disemployment." The study was prepared for the National Commission on Technology, Automation, and Economic Progress by the Bureau of Labor Statistics of the U.S. Department of Labor.

Previously the BLS has analyzed industry data to estimate the declines in employment associated with productivity increases (disemployment) and with output decreases at the industry level. This study tests the relationship between these estimates and declines in jobs at the establishment level. In addition, this study measures the statistical relationships between changes in productivity and employment and between productivity and output in terms of correlation ratios.

The BLS wishes to acknowledge the generous cooperation of the Bureau of the Census in preparing special tabulations of its basic data. These tabulations were used for developing the measures contained in this report.

The study was prepared in the Bureau's Division of Productivity Measurement, Lloyd A. Prochnow, Chief, under the general direction of Leon Greenberg, Assistant Commissioner for Productivity and Technological Developments. This study was planned and conducted and the report prepared by Benjamin P. Klotz.

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Disemployment of Labor at the Establishment Level

Introduction

Employment and Technological Change

Over the long run, technological change and increased productivity have generally contributed to economic growth and expansion of employment opportunities. In the short run, however, numerous dislocations have occurred, requiring transfer and adjustment of workers to new occupations and new industries. These short-run changes, accompanied in recent years by high rates of unemployment, have frequently led to the question, "How much unemployment is due to technological change?" A precise answer to this question may be impossible because unemployment may result from various other factors such as declining demand and output, competition, and product substitution. These and other factors may operate simultaneously and yet affect employment differently in different industries of the economy.

Process innovation (the technological change which usually results from installation of labor-saving machinery and equipment or managerial improvements) is reflected in the increased productivity (output per man-hour) of plants and industries. If the rise in output per man-hour is not accompanied by an equivalent increase in output, employment (measured in terms of total hours employed) will decline. Product substitution may result from technological change in another plant. That is, increased output and employment in one plant or industry, may take place at the expense of decreased output and employment in another—although such substitution may not be accompanied by productivity gains in any specific plant. In both types of situations, workers who are displaced and new entrants to the labor force must seek job opportunities in other occupations or in other industries.

Objective of Study

This study assesses the relative impact of productivity increases and output declines on plant employment in 17 selected 4-digit industries over various time periods. The analysis is based on information contained in a special Bureau of the Census study (their Times Series Project), a pilot project in which a time series of production statistics were compiled for the establishments in 25 selected industries. Various groupings and breakdowns of the Census data are made in this report, but in order to prevent the disclosure of individual establishment data, the number of industries for which data are presented has been reduced to 17. See appendix for a description of the scope of the study, including the specific 17 industries utilized for the analysis.

Because data for individual establishments were not readily available, previous studies on the impact of technical change have examined output, productivity, and employment at the industry level only.[1] The purpose of this study is to determine the difference (or similarity) in results obtained by using data for establishments instead of industries for estimating the impact of technical change.

Disemployment Measures

The key concept in this study is disemployment, defined as the decline in production worker man-hours associated with productivity advance (or, the inverse, decline in unit man-hours). The employment decrease of a plant or industry is split into two portions, that due to a productivity advance (disemployment) and that due to output decline.[2]

The disemployment estimates correspond to the decline in the number of jobs available in certain groups of industries or plants as a result of process innovation. These estimates are only partial indicators of total technological displacement as they do not reflect the impact of product substitution where plants or industries lose markets to technologically progressive competitors, to new products, and to new materials. This kind of technological change results in decreased output in some plants or industries and is partly accounted for in figures on decreases in employment associated with decreases in output.

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[1] Ewan Clague and Leon Greenberg, "Technological Change and Employment," *Monthly Labor Review*, July 1962, pp. 742–746. Leon Greenberg, *Technical Change, Productivity and Employment in the United States*, Organization for Economic Cooperation and Development, December 1964.

[2] See appendix for a basic description of the analytical procedure for estimating disemployment.

The total impact of direct process innovation and product substitution resulting from process innovation is approximated in this study by the gross declines in man-hours exhibited by the plants of an industry: approximated because product substitution can be caused by changes in consumer tastes as well as by technological factors.

Disemployment is not necessarily identical to unemployment resulting from process innovation. Decreases in plant or industry employment do not necessarily mean that workers are laid off and become unemployed. In some cases, employment reductions are achieved through normal attrition—deaths, retirements, and quits.

Because the industry level estimates reflect *net* disemployment among industries, the estimates may not accurately reflect the total disemployment among plants. For example, in an industry where employment increased, an estimate of disemployment based on the industry level would be zero. However, within the industry there may be a number of plants in which employment declined as a result of technological innovation. Consequently, the industry level estimate would understate the actual figure of disemployment.

On the other hand, it is possible that the industry level estimates may overstate disemployment. This situation could occur when a decline in product demand forces a low productivity (inefficient) plant to reduce its output or go out of business. If unit labor requirements and output in all other plants remain the same, the industry level estimates would indicate a decline in employment, output, and unit labor requirements, reflecting partly the shift to higher productivity establishments. In general, when the composition of industry output shifts to the high productivity plants, the industry productivity figure rises even though there may have been no improvement in any plant. For such industries, the observed rise in industry productivity implies that any employment decline is attributed to technological innovations, even when none actually occurred. Since there are sound economic reasons for expecting high productivity plants to show a relative output gain, an industry level disemployment estimate may overstate the disemployment among plants.

It is also possible that the method of analysis, using the net employment change of plants or industries over a time period, could mask disemployment that may have occurred during the intervening years. That is, a worker replaced by a machine but subseqently rehired as much as 3 years later may be excluded from a disemployment estimate which covers a 4-year period.

Summary of Findings

In this study the employment behavior of selected plants experiencing different rates of productivity advance was analyzed by correlation methods and from estimates of disemployment. Although there were several ancillary results, the main purpose of the investigation was to find if disemployment estimates based on establishment data would be different than similar estimates based upon industry aggregates. Previous studies (see footnote 1) of disemployment were based on industry data for about 200 manufacturing industries. However, it was suspected that a great deal of disemployment occurring at the plant level was not being reflected in the industry level estimates. This proposition has been tested using establishment information in 17 selected 4-digit manufacturing industries—it was found to be generally untrue.

An analysis of estimates of disemployment derived from establishment data with corresponding estimates derived from industry levels indicated. (See tables A and B.)

1. For *specific* industries there was considerable variation between the two estimates.

2. But in general, estimates derived from industry levels were neither consistently higher nor lower than estimates derived from establishment data.

3. In no specific industry did the two estimates bear a consistent relationship to one another over the various time periods studied.

Table A. Comparison of Alternative Estimates of Industry Disemployment, 1957–61

[In thousands of production worker man-hours]

Industry	Based on plant data	Based on industry data	Difference: plant minus industry
1	1,318	1,577	−259
2	3,126	4,177	−1,051
3	1,780	0	1,780
4	30,514	32,131	−1,617
5	26,250	25,532	718
6	7,078	10,340	−3,262
7	64,122	65,753	−1,631
8	2,455	4,118	−1,663
9	1,253	1,297	−44
10	1,893	1,921	−28
11	3,285	0	3,285
12	5,973	6,137	−164
13	3,590	2,577	1,013
14	890	625	265
15	1,938	0	1,938
16	3,114	6,462	−3,348
17	7,815	10,940	−3,125
Total	166,394	173,587	−6,503

Source: Estimates derived from records of the Bureau of the Census for establishments reporting in 1957 and 1961.

Table B. Comparison of Alternative Estimates of Industry Disemployment, Selected Periods

[In thousands of production worker man-hours]

Industry	Based on plant data			Based on industry aggregate data		
	1947–57	1953–59	1957–61	1947–57	1953–59	1957–61
A	810	464	972	0	0	1,044
B	4,059	3,100	2,915	5,383	1,382	3,395
C	35,790	33,412	30,165	18,088	31,264	32,442
D	29,806	22,805	25,982	56,175	39,790	25,711
E	4,730	4,563	5,868	0	0	8,417
F	2,399	3,229	1,578	821	2,571	670
G	8,517	2,783	2,864	6,389	0	5,537
H	6,558	3,712	6,023	231	4,927	9,002
Total	92,669	74,068	76,367	87,087	79,934	86,218

Source: Estimates derived from records of the Bureau of the Census for establishments reporting data for 1947 and 1961.

These findings indicate that the disemployment occurring at the establishment level in a *specific* industry cannot be reliably estimated from industry aggregates of output, employment, and productivity. However, based on the experience of 17 industries, it would seem that the establishment level disemployment occurring in all manufacturing industries can be reasonably approximated by estimates based on industry level aggregates. That is, the previous estimates of disemployment for all manufacturing, though based on industry data, are probably fairly accurate reflections of total manufacturing disemployment occurring at the establishment level.

4. Percentage differences between the two estimates for large industries were similar to the differences for small industries.

The industry correlations based on establishment data were an alternative approach to analyzing the employment-productivity relationships. They are analyzed in detail in the last section of this report, but in summary they revealed:

5. That the correlation between percentage changes in plant output and unit man-hour requirements varied considerably among industry, but was negative for 16 of the 17 industries, thus indicating that, for this limited section of 17 4-digit industries, output increases were associated with decreases in unit man-hour requirements (i.e., increases in productivity) at the establishment level.

6. The correlation between percentage changes in plant production worker man-hours and unit man-hour requirements also varied considerably among the 17 industries, but the majority of correlations fell between zero and 0.5, i.e., establishment productivity advances were associated with production worker man-hour declines.

7. The correlation between percentage changes in production worker man-hours and unit man-hour requirements showed no tendency to be lower over the 1947–61 period than during any of the subperiods. Thus, plant output did not expand sufficiently in the longer period to negate the impact of increased productivity upon production worker man-hours.

Analysis of Disemployment Experience

Ratios Used in the Analysis

Several ratios were used for the analysis of productivity advance and disemployment. Some of these ratios explain the rate of incidence of disemployment rather than its absolute magnitude. The disemployment rate for a specified period is defined as the ratio obtained by dividing disemployment (D) during the period by production worker man-hours (H) at the beginning of the period. The importance of studying disemployment rates, whether derived from plant level estimates (D_p/H) or industry aggregates (D_i/H), is illustrated by the seemingly simple question, "Is disemployment a greater problem in industry x or in industry y?" Of course, if industry x's disemployment is twice as large as y's, this is an important fact. The absolute magnitude of the human problem is emphasized. For example, manpower retraining programs might be geared to meet this problem; also, since the retraining needs and capabilities of industry x workers may differ generally from that of the y workers, the composition of such programs will be affected. But, if industry x is twice as large as y the impact of disemployment does not weigh more heavily on the x workers, in fact the rate (or incidence) of disemployment is the same in both industries. In a relative sense then the problem is no greater in x than in y.

When analyzing the causes of plant level disemployment, a strong relationship is found between the amount of initial employment and the subsequent volume of disemployment, the correlation being 0.87 for the 1957–61 period. This means that the larger industries have greater disemployment volumes but indicates nothing about their rate of disemployment.

This study concentrates on the potentially more fruitful course of analyzing disemployment rates by plants among the industries. Associations between these rates and such variables as the industry's rate of productivity or output advance could lead to meaningful results. The technically progressive industries need not experience disemployment if their increase in output is sufficient to offset their lower unit labor requirements. Correlations between industry productivity advance and their D_p/H were calculated in this study to analyze this possibility.

As explained in the introduction it is possible for estimates of disemployment based on industry aggregates to be greater or less than aggregate disemployment estimates built up from plant data. The measure D_p/D_i, the ratio of plant level to industry level disemployment, was computed to ascertain the degree of divergence between the two measures and to buttress previous more comprehensive studies which focused upon industry level disemployment.

The disemployment rates do not exhaust the statistical information about labor displacement in an industry. The concept of the gross displacement rate (gross employment declines as a percent of initial employment=GD/H) includes the plant level disemployment rate (D_p/H) plus the rate of labor displacement caused by plant output declines. Gross displacement then refers to the gross employment declines of plants, whether caused by productivity advance or output decline, and is the raw figure from which the disemployment sum is distilled.

Rates of gross displacement can be compared with disemployment rates to determine the percent of the gross declines which are allocated as disemployment, that is, the D_p/GD ratio.

The correlation between percentage changes in employment and unit man-hours is an alternative measure of the impact of technological change upon employment. Positive correlations signify that plant employment declined as unit man-hours were reduced; the expanding output associated with falling UMH was not sufficient to prevent an employment decline.

Disemployment: 1957–61

Comparing plant level (D_p) with industry level disemployment (D_i), 1957–61, the number of industries where:

D_p exceeded D_i by more than 10 percent =6.
The D_p, D_i difference was less than 10 percent =6.
D_p was less than 90 percent of D_i=5.

For all 17 industries combined, plant level disemployment was only four percent less than the industry level figure.[3] The former measure is considered more appropriate when analyzing the impact of technical change on employment. Changing manpower requirements of the employer unit, the establishment, are more closely related to plant level behavior than to the movement of industry aggregates. However, this difference is so small that either estimate may be used. Table 1 summarizes the statistics for 17 industries for which information was available over the 1957-61 period.

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[3] The industry level disemployment rates (col. 1 of table 1) were derived from table 1–a which gives a detailed breakdown of each industry's change in production worker man-hours.

During 1957-61, the industries having the highest disemployment rates generally experienced above average productivity gains for the period, and the industries with the lowest disemployment rates had relatively low (or no) productivity gains. The rank correlation between the rate of industry productivity advance and the plant level disemployment rate was 0.85. Evidently, technical change influenced the disemployment rate quite strongly in this array of industries. This does not necessarily mean that the typical *plant's* productivity advance and its disemployment rate were correlated, but that there was a statistical relationship at the industry level. Any output-expansion effect of improved productivity was apparently not strong enough to prevent disemployment.

Total capital expenditures (CE) of plants having disemployment were compared with the CE of the remaining plants of each industry during the 1957-61 period. It was anticipated that CE per man-hour would be greater among the plants experiencing disemployment. However, this was not the case for the industries covered in this study. It would appear that plant disemployment did not result from heavy capital spending (which would presumably reflect substitution of machines for labor). The plants which did such heavy spending were not those which typically experienced disemployment.

There appeared to be no relation between the plant disemployment rate and the rate of gross employment decline (table 1, col. 5). This was somewhat surprising since the latter is comprised of the former plus the employment decline associated with plant output declines. It was like finding there was no correlation between a quantity "w" and a quantity "w+x". The x variable, in this case the employment decline associated with plant output declines, could not be positively correlated with w and w could not dominate x vis-a-vis size.

Coefficients of correlation between the percentage changes in plant productivity and output, as well as productivity and employment, are an alternative method for analyzing the productivity-employment relation (table 1, cols. 6 and 7). The productivity-output relations were high and positive for three industries. Only one industry showed productivity and output moving in the opposite direction. Only two industries had negative unit man-hour-employment correlations. That is, progressive plants expanded employment in these two industries. Both also had a high rate of gross employment decline (table 1, col. 4). There does not appear to be any theoretical reason for this particular association since a third industry, which had a high rate of gross employment decline, experienced no negative correlation.

Size distribution of absolute values of correlation coefficients

	Productivity-output	*Productivity-employment*
0.249 or less	4	5
0.250-0.500	9	8
0.501-0.750	4	4

Although there was considerable variation among industries, the productivity-output association was generally stronger than that for productivity and employment.

Disemployment Analysis for Reduced Sample of Industries

Disemployment: 1947–57

A consistent set of data for eight industries were analyzed over the 1947–61 period to test the time stability of the relations analyzed in table 1. The plant data of the Census Bureau Times Series Study was more restricted in the years before 1954, and not only was the industry coverage reduced but the list of plants included in each industry was more selective. Consequently, the industry analyses in this and the following two sections are based on data for fewer establishments than for their apparent counterparts in the previous section. The three periods 1947–57, 1953–59, and 1957–61 were selected for comparison, the first being a period of output growth and the last a period of little output change.

Table 2 summarizes information derived for the 1947–57 period for only eight industries. Because these industries are only a small part of all manufacturing activity, the results should be interpreted with care.

Plant level disemployment estimates exceeded industry level estimates[4] in 6 of the 8 industries, but when the two estimates were aggregated and compared, D_p for the group of eight industries exceeded D_i by only 6.4 percent. In the aggregate the estimates were close even though they differed widely for the various industries.

D_p/H expresses disemployment derived from plant level data as a percent of initial employment. The D_p/H statistic of column 2 is variable among industries, ranging from 0.18 to a low of 0.07. Significantly, these were the high and low industries, respectively, vis-a-vis productivity advance. The D_i/H statistic exhibited even more variability. There appears to be some association during the 1947–57 period between the incidence of plant level disemployment, D_p/H, for each industry and the industry's rate of decline in unit man-hours. For the eight industries, the coefficient of rank correlation was 0.63 between the D_p/H column and the percentage change in unit man-hour column.

Column 4 measures the incidence of gross plant employment declines, GD/H. The incidence of these gross declines display considerable variation between the eight industries, ranging from 0.33 to only 0.11. Paradoxically, these gross declines are not associated with plant level disemployment though they are related to industry level disemployment.[5]

Column 5 expresses plant level disemployment as a percent of the gross plant employment decline. In one industry D_p/GD was unity; there was no plant employment decline associated with an output decline in this industry. All the employment declines were assigned to process innovation (disemployment). The two lowest D_p/GD industries (those where output declines had the greatest impact on employment) experienced below average output increases and over half their plants suffered output declines. As would be expected, the industries with higher incidences of disemployment experienced higher D_p/GD ratios, but the correlation was not very strong ($R_s=0.54$).

Correlation coefficients are presented in columns 6 and 7. They are based on unweighted plant data in each industry. There appears to be more variability in the column 7 coefficient, relating the percent change in employment to the percent change in productivity, than in those of column 6, which relate the percent change in output to the percent change in productivity. It seems that the employment-productivity correlations for the eight industries, in addition to exhibiting variability, are not closely related to any of the other variables appearing in the table. Significantly, they are not related to the incidence of disemployment, D_p/H, the coefficient of rank correlation being only 0.29.

For this time period, the productivity-employment correlation derived for an industry is then not a reliable guide to the incidence of disemployment in that industry. However, if weighted[6] correlation coefficients had been computed, the correspondence with the incidence of disemployment might have been better.

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[4] The industry level disemployment rates for 1947–57 (col. 1 of table 2) were derived from table 2–a which analyzes in detail the production worker man-hour change of each of the eight industries.

[5] A Spearman coefficient of rank correlation was computed by ranking the eight industries by their GD/H, D_i/H, and D_p/H. The ranks of GD/H and D_i/H were correlated ($R_s=0.88$) as were GD/H and D_p/H ($R_s=0.29$). $R_s=1-\frac{6\,\Sigma\,d^2}{N\,(N^2-1)}$ where N=number of observations and d=rank differences.

[6] The percentage change observations could have been weighted by plant employment. See appendix. An equal weighting of plants, the method used in this study, can create problems of interpretation. Assume two industries exhibit the same correlation between percentage change in unit labor requirements and percentage change in employment but that the average plant size in one industry is twice that of the other. Then the disemployment estimate in the one industry could easily be twice that of the other. The correlation coefficient of this study relates the average association between *percentage* changes in plant employment and in productivity, not absolute amounts.

Disemployment: 1953–59

Table 3 summarizes the same information as table 2, but for the 1953–59 period. During this period also, plant level disemployment exceeded the industry level measure[7] in six of the eight industries, but the opposite held very strongly in another industry. In fact, the sum of D_p for the eight industries was only 93 percent of the sum of D_I, due to the impact of that one industry.

A ranking of the industries by their plant level disemployment rate (D_p) and by their rate of productivity advance revealed a rank correlation coefficient of 0.65, very close to the 0.63 for the 1947–57 period. This indicated that the technically progressive industries, as during 1947–57, tended to have higher disemployment rates. However, the sample size was extremely small since only eight industries were covered.

The rates of gross employment decline, column 4, ranged from 38 percent to 10 percent. Generally, the industries which experienced high rates of gross decline did not experience high rates of plant level disemployment (the rank correlation being −0.39). Evidently, declining output had a more powerful influence on the gross plant employment declines than did disemployment. However, the puzzling relation between industry level disemployment and gross plant employment declines is evident in this time period also. The rank correlation of 0.55, is not strong, though significantly different from zero, and the relation may be coincidental rather than causal.

An examination of the correlation coefficient again shows greater variability in the employment-productivity relationship than in the output-productivity relations. Three of the former relationships are actually negative, meaning that employment increased on the average as unit man-hours dropped. This would require a large expansion of output, and this did occur in the three industries. Their output, unit man-hour relations were −0.477, −0.560, and −0.556. So, on the average, output expanded as unit man-hours dropped.

The employment-productivity relation of column 7 again does not appear to be related to any column on the table 4, although the D_p/H column has a 0.46 rank correlation with column 7. This is stronger than the 0.29 of the 1947–57 period but still not very significant. These two alternative measures of the technical change-employment relationship were not too consistent with one another.

Disemployment: 1957–61

Table 4 traces the group of eight industries through 1957 to 1961. As for previous periods, the eight exhibited differences between their industry level[8] and their plant level disemployment estimates. But, in this period the former exceeded the latter in six cases, reversing the behavior of the 1947–57 period. Column 3 of table 4 shows that the aggregate plant level estimate was 89 percent of the aggregate industry level estimate; as in the other periods, they were quite close.

Whereas the group's output rose 44 percent from 1947 to 1957, it rose only 7 percent through 1961. The average annual rates of the group are compared:[9]

Group of eight industries—Annual rates

	1947–57	*1957–61*
Employment	−1. 4	−5. 0
Output	4. 4	1. 75
Unit man-hours	−4. 0	−6. 25
Plant level disemployment	1. 5	3. 5

Output decelerated and productivity accelerated[10] in the later period causing employment to drop more rapidly than before. The rate of disemployment based on plant level estimates more than doubled.

There was little change in the rankings over the two periods when industries were ranked by their plant level disemployment rate (compare the col. 2 behavior in tables 2 and 4).[11] However, rather large changes occurred in the rankings vis-a-vis the incidence of gross employment declines. For example, the highest incidence industry over 1947–57 experienced the lowest incidence during 1957–61. There was also a weak correlation, 0.43, when the relative ranks of the industries were compared for the D_p/GD variable over the two periods. That is, disemployment did not account for a constant fraction of the gross employment declines either as between industries or for the same industry over time. Thus, in summary, the effect of output declines on employment was extremely variable vis-a-vis the disemployment effect on employment.

The values of correlation coefficients relating the percentage change in plant employment and unit labor requirements for the eight industries were generally higher for the 1957–61 period than for the 1947–57 period. The coefficients were higher in five industries, and especially in one industry where the relation changed from −0.039 to 0.440, as time progressed. Also, this is the only period where a ranking of the eight productivity-employment correlation coefficients corresponded with a ranking of the industries by their rate of disemployment. The Spearman coefficient was 0.79, meaning that these two alternative measures of the impact of technology upon employment were consistent for the 1957–61 experience.

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[7] Industry level disemployment rates for 1953–59 (col. 1 of table 3) were derived from table 3–a.

[8] Industry level disemployment rates for 1957–61 (col. 1 of table 4) were derived from table 4–a.

[9] Although these are not compound rates of change, they do indicate the basic differences between the two periods.

[10] An acceleration of unit man-hours downward is equivalent to an acceleration of productivity upward.

[11] The Spearman coefficient was 0.80.

Correlation Analysis

Introduction

The relation between technological advance, output, and productivity can be examined by correlation techniques also, but the results must be interpreted with care. During 1957–61, for example, when unit man-hours were correlated with output for 23 industries, the result was negative for 22 of the industries; only one was positive.[12] This does not mean the UMH decline caused the output advance or vice versa, the chains of causation run both ways. The findings do indicate that declining UHM requirements were associated with expanding output among the plants of 22 of the industries. These two movement had offsetting effects on production worker man-hours (PW MH).

The 23 industries for which separate correlations are given are:

SIC number	*Industry title*
3612	Transformers
3519	Internal combustion engines
3392	Nonferrous forgings
3391	Iron and steel forgings
3362	Brass, bronze, copper castings
3352	Aluminum rolling and drawing
3351	Copper rolling and drawing
3334	Primary aluminum
3333	Primary zinc
3331	Primary copper
3323	Steel foundries
3322	Malleable iron foundries
3315	Steel wire drawing
3313	Electrometallurgical products
3312	Blast furnaces and steel mills
3241	Hydraulic cement
3011	Tires
2911	Petroleum refining
2823	Cellulosic man-made fibers
2822	Synthetic rubber
2272	Tufted carpets and rugs
2271	Woven carpets and rugs
2092	Soybean oil mills

Conclusions may be drawn as to whether plant output expanded enough to offset the effect of declining plant UMH requirements on plant PWMH. Correlating the percentage change in plant UMH with the percentage change in plant PWMH for each industry, only two industries exhibited negative correlation values. That is, on the average, only in two industries was the increase in plant output which occurred simultaneously with the decline in plant UMH, strong enough to result in an increase in PWMH. In these two industries, the average plant behavior meant that PWMH increased as UMH requirements fell. One would expect very little job displacement from process innovation (the disemployment concept) or product innovation in these expanding industries. That is, the greater the output expansion among the plants of an industry, the less the chance of an employment decline and the less the change of disemployment. The disemployment estimates and techniques have explored these relationships in greater detail in the previous parts of this report.

Analysis of Correlation Coefficients

Employment and Productivity. Previous statistical studies of the correlation between unit labor requirements (ULR) changes and employment changes have used industry information. Over a specified time period each industry in a group of industries was treated as an observation and a correlation coefficient was derived for the industry group. For example, the correlation between ULR changes and production worker man-hour changes for 200 manufacturing industries over the 1957–61 period was 0.20. There was a slight tendency for man-hours to decline as unit labor requirements declined.

The general conclusions based on industry level analysis seem to be:[13]

1. Correlations between declines in unit labor requirements and man-hour declines are low, typically between zero and 0.25.
2. When longer time periods are examined, these correlations approach zero, and in some cases declining unit labor requirements are associated with man-hour increases.

Though it is based on a nonrandom sample of industries, this study attempts to determine whether the industry level pattern repeats itself at the establishment level. In certain industries, using establishment data, the correlation between changes in unit labor requirements (the reciprocal of productivity) and changes in production worker man-hours is quite high.[14] There are correlations for 23 industries over the 1957–61 period and five of these exceed 0.50. Fourteen of the correlations exceeded 0.25. These results indicate that there can be a significant productivity-employment relationship at the plant level in some industries over a short time period.

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[12] See appendix, table 6. These are the industries of the Census Bureau Time Series Project with two of the 25-industry correlations withheld because of insufficient observations.

[13] See George Terborgh, *The Automation Hysteria,* Machinery and Allied Products Institute, New York, 1965, appendix A.

[14] See appendix, tables 6 through 10.

The group of 25 industries is not a random sample of all manufacturing since 14 of them are in SIC group 33, the Primary Metals Industries. However, when a correlation was obtained based on *all* the plants in the 25 industries over 1957–61 (some 1,600 establishments) the statistic was 0.21. This compares with a 0.20 figure based on the behavior of 200 4-digit manufacturing industries over the same period.[15] These results are surprisingly similar even though based on different levels of aggregation and different industry groupings.

A longer time period was studied to see if the unit man-hour versus production worker man-hours correlation declined as the period lengthened. Plants for which data were available back to 1947 were examined. The Census Bureau Time Series Project was less extensive for this earlier year and only 15 industries could be examined. Correlations were withheld on four of these industries because of insufficient observations, leaving 11 industries for analysis.

Of the correlations for the 1947–61 period only one exceeded 0.5, but six exceeded 0.25. As for the shorter periods, during 1947–57, none exceeded 0.5, but six exceeded 0.25; for 1953–59, one exceeded 0.5 and only three exceeded 0.25; and during 1957–61, one exceeded 0.5 but seven exceeded 0.25. Thus, when all 11 industries are considered it can not be said that the correlations were smaller for the longer period 1947–61 than for the shorter subperiods.

Perhaps a *given* industry might experience a lower correlation in the long run than in the short run. However, only 2 industries of the 11 studied exhibit correlations which are lowest for the longest period. That is, their 1947–61 correlation was lower than their 1947–57 or 1953–59 or 1957–61 correlations. But the figures for one industry are quite unreliable since the number of observations is less than 30 and the correlation coefficients have high standard errors. The other industry also has rather high standard errors in relation to the correlation coefficients, so even here it would be dangerous to conclude that the correlation coefficient declined as the time period lengthened.

On the other hand, the longer run (1947–61) correlation of unit man-hours versus production worker man-hours was *greater* than any of the three subperiod correlations for 5 of the 11 industries. The results for these five industries are of varying degrees of reliability with perhaps only one showing a significantly greater long run correlation.

The general conclusion must be that for the 11 industries studied there was no tendency for the plant level productivity-employment correlation to be weaker for longer time periods. It would seem that *in these industries* the progressive plants were not able in the long run to expand their output enough to prevent their production worker man-hours from declining. But it is not appropriate to generalize this result to all industries because the 11 industries studied are highly selective and do not cover very long time periods. Further, the choice of initial and terminal years has been necessitated by data availability rather than theoretical considerations such as the desire to cover a complete business cycle. What has been brought to light is the differing impact of technical change upon employment among various industries. In any event, plant level analysis seems more relevant for this purpose because technical progress may displace workers from a plant directly, but only indirectly from an industry.

Output and Productivity. The output-unit man-hour requirements correlations are ancillary to the foregoing analysis but interesting in their own right. As in the productivity-employment correlations there is a tendency for the longer run (1947–61) output-UMH association to be closer to zero. For none of the 11 industries compared in tables 7–10 is the 1947–61 correlation stronger than each of its subperiod correlations. In fact, 5 of the 11 industries have 1947–61 correlations which are weaker than any of their subperiod correlations. These results are consistent with the previous finding of a stronger productivity-employment relation in the long run.

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[15] Leon Greenberg, *Technological Change, Productivity and Employment in the United States*, Organization for Economic Co-Operation and Development, December 1964.

APPENDIX

Technical Note

Scope of Study

This study is based on special tabulations of establishment data from the Bureau of the Census. The data are those included in a Time Series Project of the Bureau of the Census which was undertaken to study the factors involved in the growth and structural change of the industrial economy in the United States. The study makes use of the *Census of Manufactures* records, the *Annual Survey of Manufactures*, and special supplemental Census surveys.

The time series study will eventually include all manufacturing and mineral industries. Initially, however, 25 manufacturing industries have been selected representing the major portion of 2-digit industry group 33 and a few industries representative of various other manufacturing industry groups. The establishments are classified on the basis of the industry code in the 1958 *Census of Manufactures* (1957 *Standard Industrial Classification*).

The establishments included are those in the *Annual Survey of Manufactures* sample. Therefore, the study includes nearly all large establishments (those with more than 100 employees in 1958) and a probability sample of smaller establishments. A few small establishments with incomplete records have been omitted from the tabulations.

Even though great care was taken in compiling the plant data, reporting errors inevitably arose. Some of these were of a gross nature and resulted in exclusion of the relevant establishment from the tabulations. Fortunately, as seen in the accompanying table 5, industry coverage was not reduced significantly except in a few industries.

The plant records for 25 industries cover the 1954–61 period. However, when these records were extended back to 1947 in 15 of the industries, they proved less comprehensive. Most of this reduction was due to a change in the sample for the *Annual Survey of Manufactures* in 1953. Some plant records could not be traced back to 1947. Plants were dropped, and, thus, industry coverage was further reduced. See table 5 for coverage ratios.

Comparability of Industry Aggregate Data With Other BLS Studies

The "industry measures" of productivity, output, and employment employed in this study, as seen from table 5, are based on a subset of the plants in each industry. Although the plants in the Census Time Series Project were selected by a stratified random sample, the plant list of this study is not random. By necessity plants with unreliable data were eliminated. Therefore, a comparison of these figures with other published output, productivity, and employment series may show differences because the industry coverage is different.

Furthermore, this study's output measure is adjusted gross production divided by a price index, whereas the typical BLS study attempts to measure output as physical units weighted by unit labor requirements. There is a conceptual difference between the output measures of the two methods.

Periods Selected

Three overlapping but dissimilar time periods were chosen for the disemployment study. To have the analysis cover a recent period, 1957–61 was chosen. Manufacturing employment rose during 1947–57, but declined over 1953–59. The periods differed in that manufacturing output rose more sharply in the early years than in the later years. The periods were chosen for consistency with previous studies on industry data. See, Ewan Clague and Leon Greenberg, "Technological Change and Employment," *Monthly Labor Review*, July 1962, pp. 742–746; Leon Greenberg, *Technological Change, Productivity, and Employment in the United States*, Organization for Economic Co-Operation and Development, December 1964.

Data Definitions

a. Output=real adjusted gross production=value of shipments plus net change in inventory and work-in-process, adjusted for price change.

(Unpublished BLS price indexes were used for this purpose.)

b. Employment = production worker man-hours, abbreviated as PWMH.

c. Productivity = output divided by employment (i.e., production worker man-hours).

d. Unit Man-Hours = employment divided by output, abbreviated as UMH.

e. Plant = establishment (as opposed to "firm").

Data Limitations

Some causes for divergence between computed output and productivity and actual output and productivity may be cited. The output of each plant was adjusted by an industry price index. If the product mix produced by each plant was the same as the industry mix, the price index would then apply with equal validity to every plant. Product mixes differ, however, and the common price deflation introduces an element of error into the plant output measures. The extent of this error is unknown.

The price indexes are computed from available wholesale price indexes of commodities, and it was not possible to price every product of every industry. Although the proportion of products included in the price index varies among the industries, the coverage was generally above 70 percent of the value of production.

There is the possibility that the correlation coefficients are biased upward. They are based on *reported* PWMH and output, not *actual* PWMH and output. The output-unit man-hours correlation in effect puts the reported output measure on both sides of an equation, and this reported output can be thought of as the true output plus a reporting error. The actual correlation is $Q+E$ vs. $(H+V)/(Q+E)$ where Q is true output, H are true man-hours, E is the reporting error of Q, and V is the reporting error of H. Since E influences both terms, it causes some degree of spurious correlation between them, i.e., as E increases, $Q+E$ increases, but $(H+V)/(Q+E)$ decreases.[1] Any negative correlation between the true Q and the true H/Q would be made even closer to minus one by the error term on both sides. When $H+V$ is correlated with $(H+V)/(Q+E)$, the true correlation, by a similar argument, is forced closer to plus one because of the action of V.

The correlation coefficients and their standard errors are subject to further limitations. Because it was necessary to exclude data for some establishments, we do not have a probability sample of the plants of each industry. This distribution of the observations on the variables is not normal, and in many instances the number of plant records available for analysis is small. For these reasons the usual interpretation of the significance of the R values would be invalid. It is necessary to interpret the measures with care.

Detailed Analytical Procedure

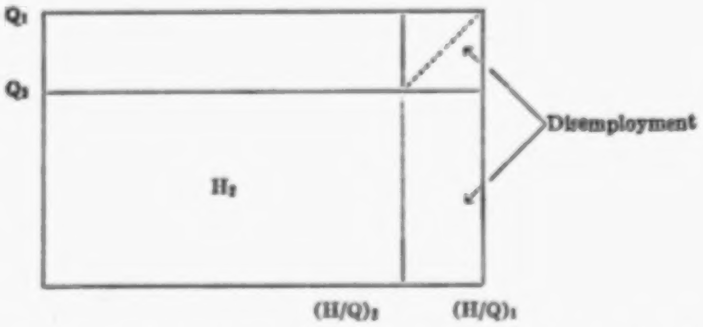
Disemployment Study. For purposes of this analysis, the plants were divided into two broad groups—those with PWMH decreases and those with increases. For the latter group there is, of course, no net loss in employment associated with productivity gains (although there may have been such an association among occupational groups or individual departments within the plants).

The plants with production worker man-hour decreases were divided into three subgroups:

Subgroup 1. Output increased but unit man-hours decreased. The entire decrease in man-hours is associated with the decrease in UMH, and is considered disemployment.

Subgroup 2. Output decreased but unit man-hours increased. Output was responsible for the man-hour decline.

Subgroup 3. Both output and unit man-hours decreased. Part of the employment decline is disemployment—that part due to the decline in UMH. The remainder of the man-hours decrease is associated with the decline in output. The diagram illustrates the amount of disemployment when both output and unit man-hours fall. Q_1 is initial output and $(H/Q)_1$ is initial unit man-hours.



Disemployment, as defined, can occur only in subgroups one and three. The entire PWMH decline in subgroup one, but only a part of the subgroup three decline, is disemployment. Subgroup one plants experienced a man-hour decline even though output increased. The decrease must have been due to technical change (process innovation). In the subgroup three, plant man-hours decreased because their output as well as their unit man-hours were declining. The decrease was correspondingly split into an output effect and a productivity effect, the latter being the disemployment figure for the plants.

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[1] Unless V increases proportionately to E, in which case $H+V/(Q+E)=H/Q$ and no bias is introduced. Probably V and E move together and this tends to minimize any bias in the correlation coefficients. But the association between V and E is unknown and some bias probably exists in the correlation results of this study.

For analysis purposes, the plants with PWMH increases were also divided into three subgroups:

1. Output and UMH increased.
2. Output increased but UMH decreased.
3. Output decreased but UMH increased.

Since these three groups experienced no man-hour declines, disemployment for them must be zero.

Correlation Analysis. Using plant data for each of the 25 industries, Pearsonian correlation coefficients were derived for various time periods between the percentage changes in (1) productivity and output, and (2) productivity and employment. Specifically, for 1957–61, 1953–59, 1947–57, and 1947–61, unweighted (that is, plants were weighted equally even though they differed widely in size) plant data were used as observations.

Other correlations mentioned in the text, such as that between the industry disemployment rate and the industry rate of productivity advance, are Spearman rank correlations. They are distinguished by being based upon industry, rather than plant observations.

TABLE 1. ANALYSIS OF OUTPUT, EMPLOYMENT AND PRODUCTIVITY RELATIONSHIPS, 1957–61[1]

Industry	Percent change			D_1/H	D_2/H	D_2/D_1	GD/H	D_2/GD	R_a. H/Q	R_b, H/Q
	Employment	Output	Unit man-hours	1	2	3	4	5	6	7
1	−18	10	−26	0.18	0.15	0.84	0.21	0.71	−0.625	0.[illegible]56
2	−25	−14	−13	.12	.09	.75	.26	.34	−.499	−.256
3	7	66	−36	.00	.10		.15	.65	−.420	.306
4	−17	9	−24	.17	.16	.95	.19	.83	−.532	.399
5	−17	14	−27	.17	.18	1.03	.20	.89	−.164	.507
6	−15	3	−18	.15	.11	.68	.21	.53	−.525	.297
7	−23	−17	−7	.07	.07	.98	.25	.28	−.384	.209
8	−35	−23	−16	.16	.10	.60	.37	.27	−.647	−.221
9	−5	3	−8	.05	.05	.97	.12	.41	−.285	.369
10	−16	−11	−6	.05	.05	.99	.19	.27	+.012	.510
11	−33	−35	+2	.00	.04		.40	.10	−.320	.098
12	−10	8	−16	.10	.10	.97	.17	.59	−.396	.309
13	−4	11	−13	.04	.06	1.39	.15	.40	−.151	.531
14	−7	10	−7	.07	.10	1.42	.22	.45	−.017	.621
15	−27	−31	+6	.00	.03	14.36	.25	.12	−.366	.172
16	−18	−9	−10	.09	.04	.53	.24	.17	−.288	.219
17	−27	−8	−21	.20	.14	1.60	.32	.44	−.314	.446
Total	−21	−4	−17	0.09	0.09	0.96	(2)	(2)	−0.463	0.208

Column 1: Industry level disemployment/Initial production worker man-hours (i.e., PWMH 1957).
2: Plant level disemployment/Initial production worker man-hours.
3: Ratio of No. 2 to No. 1.
4: Gross plant PWMH declines/Initial PWMH.
5: Plant level disemployment/Gross plant PWMH declines.
6: Correlation between the percentage changes in plant output and unit man-hours.
7: Correlation between the percentage changes in plant PWMH and unit man-hours.

[1] Based on establishments for which data were available during 1954–61.
[2] Not available.

TABLE 1–a. RELATIONSHIP BETWEEN CHANGES IN EMPLOYMENT AND CHANGES IN UNIT MAN-HOURS, SELECTED INDUSTRIES, 1957–61[1]

Industry	Number of establishments	Total production worker man-hours		Change in total production worker man-hours					
				Total		Associated with decrease in—			
						Unit man-hours		Output	
		1957	1961	Actual	Percent	Actual	Percent	Actual	Percent
1	49	8,576	6,999	−1,577	−18.4	−1,577	−18.4	0	0
2	27	34,545	25,741	−8,804	−25.5	−4,177	−12.1	−4,627	−13.4
3	52	18,494	19,796	1,302	7.4	0	0	0	0
4	207	194,536	162,405	−32,131	−16.5	−32,131	−16.5	0	0
5	62	148,889	123,357	−25,532	−17.1	−25,532	−17.1	0	0
6	162	67,364	57,024	−10,340	−15.3	−10,340	−15.3	0	0
7	230	983,085	757,920	−225,165	−22.9	−65,753	−6.7	−159,412	−16.2
8	29	25,060	16,195	−8,865	−35.4	−4,118	−16.4	−4,747	−18.9
9	59	25,457	24,160	−1,297	−5.1	−1,297	−5.1	0	0
10	55	35,162	29,478	−5,684	−16.2	−1,921	−5.5	−3,763	−10.7
11	136	93,655	62,539	−31,116	−33.2	0	0	−31,116	−33.2
12	66	60,964	54,827	−6,137	−10.1	−6,137	−10.1	0	0
13	71	70,386	67,809	−2,577	−3.7	−2,577	−3.7	0	0
14	42	8,793	8,168	−625	−7.1	−625	−7.1	0	0
15	91	59,205	43,474	−15,731	−26.6	0	0	−15,731	−26.6
16	43	69,231	56,713	−12,518	−18.1	−6,462	−9.3	−6,056	−8.7
17	46	54,730	39,705	−15,025	−27.5	−10,940	−20.0	−4,085	−7.5
Total	1,427	1,958,132	1,556,310	−401,822	−20.5	−173,587	−8.9	−229,537	−11.7

[1] Based on establishments for which data were available during 1954–61.

SOURCE: Census Bureau Time Series Project.

TABLE 2. ANALYSIS OF OUTPUT, EMPLOYMENT AND PRODUCTIVITY RELATIONSHIPS, 1947–57[1]

Industry	Percent change			D_i/H	D_p/H	D_p/D_i	GD/H	D_p/GD	R_q, H/Q	R_h, H/Q
	Employment	Output	Unit man-hours	1	2	3	4	5	6	7
A	+32	+179	−53	0.00	0.18	------------	0.18	1.00	−0.403	0.340
B	−15	+21	−24	.15	.11	0.75	.28	.40	−.288	.042
C	−9	+63	−44	.09	.18	1.98	.21	.85	−.303	.411
D	−29	−2	−27	.27	.14	.53	.33	.43	−.287	.237
E	+4	+48	−30	.00	.09	------------	.11	.82	−.503	.388
F	−3	+11	−12	.03	.07	2.92	.15	.48	−.377	.072
G	−9	+22	−26	.09	.12	1.33	.28	.43	−.389	.072
H	−1	+38	−28	.01	.15	28.40	.19	.77	−.271	−.039
Total	−14	+44	−40	0.14	0.145	1.06	(2)	(2)	(2)	(2)

Column 1: Industry level disemployment/employment 1947 = D_i/H.
2: Plant level disemployment/employment 1947 = D_p/H.
3: Plant level disemployment/industry level disemployment = D_p/D_i.
4: Gross declines in plant employment/employment 1947 = GD/H.
5: Plant level disemployment/gross declines in plant employment = D_p/GD.
6: Correlation between percentage changes in plant output and unit man-hours = R_q, H/Q.
7: Correlation between percentage changes in plant employment and unit man-hours = R_h, H/Q.

[1] Based on establishments for which data were available during 1947–61.
[2] Not available.

TABLE 2–a. RELATIONSHIP BETWEEN CHANGES IN EMPLOYMENT AND CHANGES IN UNIT MAN-HOURS, SELECTED INDUSTRIES, 1947–57[1]

Industry	Number of establishments	Total production worker man-hours		Change in total production worker man-hours					
				Total		Associated with decrease in—			
						Unit man-hours		Output	
		1947	1957	Actual	Percent	Actual	Percent	Actual	Percent
A	21	4,487	5,939	1,452	32.4	0	0	0	0
B	19	35,329	29,946	−5,383	−15.2	−5,383	−15.2	0	0
C	143	194,490	176,402	−18,088	−9.3	−18,088	−9.3	0	0
D	43	205,562	145,589	−59,973	−29.2	−56,175	−27.3	−3,798	−1.8
E	117	52,080	54,242	−2,162	−4.2	0	0	0	0
F	46	32,064	31,243	−821	−2.6	−821	−2.6	0	0
G	33	70,208	63,819	−6,389	−9.1	−6,389	−9.1	0	0
H	23	44,827	44,596	−231	−0.5	−231	−0.5	0	0
Total	445	639,047	551,776	−87,271	−13.7	−87,087	−13.6	−3,798	−0.1

[1] Based on establishments for which data were available during 1947–61.

SOURCE: Census Bureau Time Series Project.

TABLE 3. ANALYSIS OF OUTPUT, EMPLOYMENT AND PRODUCTIVITY RELATIONSHIPS, 1953–59[1]

Industry	Percent change			D_i/H	D_p/H	D_p/D_i	GD/H	D_p/GD	R_q, H/Q	R_h, H/Q
	Employment	Output	Unit man-hours	1	2	3	4	5	6	7
A	12	73	−35	0.00	0.09	------------	0.10	0.89	−0.302	0.639
B	−5	18	−19	.05	.11	2.24	.20	.56	−.477	−.022
C	−17	24	−33	.17	.18	1.07	.22	.83	−.422	.415
D	−22	1	−24	.22	.13	.57	.27	.48	−.312	.246
E	1	26	−20	.00	.09	------------	.13	.70	−.480	.423
F	−34	−29	−8	.06	.08	1.26	.35	.23	−.560	−.008
G	−18	−18	+1	.00	.03	------------	.27	.11	−.556	−.414
H	−32	−24	−11	.10	.08	.75	.38	.21	−.272	.209
Total	−18	14	−29	.13	.12	.93	(2)	(2)	(2)	(2)

Column 1: Industry level disemployment/employment 1953=D_i/H.
2: Plant level disemployment/employment 1953=D_p/H.
3: Plant level disemployment/industry level disemployment =D_p/D_i.
4: Gross declines in plant employment/employment 1953=GD/H.
5: Plant level disemployment/gross declines in plant employment =D_p/GD.
6: Correlation between percentage changes in plant output and unit man-hours=R_q, H/Q.
7: Correlation between percentage changes in plant employment and unit man-hours=R_h, H/Q.

[1] Based on establishments for which data were available during 1947–61.
[2] Not available.

TABLE 3–a. RELATIONSHIP BETWEEN CHANGES IN EMPLOYMENT AND CHANGES IN UNIT MAN–HOURS, SELECTED INDUSTRIES, 1953–59[1]

Industry	Number of establishments	Total production worker man-hours		Change in total production worker man-hours					
				Total		Associated with decrease in—			
						Unit man-hours		Output	
		1953	1959	Actual	Percent	Actual	Percent	Actual	Percent
A	23	5,401	6,063	662	12.3	0	0	0	0
B	20	29,276	27,894	−1,382	−4.7	−1,382	−4.7	0	0
C	150	188,318	157,054	−31,264	−16.6	−31,264	−16.6	0	0
D	44	177,156	137,366	−39,790	−22.5	−39,790	−22.5	0	0
E	124	52,917	53,436	519	1.0	0	0	0	0
F	47	41,073	27,056	−14,017	−34.1	−2,571	−6.3	−11,446	−27.9
G	35	80,677	66,413	−14,264	−17.7	0	0	−14,264	−17.7
H	26	48,184	32,702	−15,482	−32.1	−4,927	−10.2	−10,555	−21.9
Total	469	623,002	507,984	115,018	−18.5	−79,934	−12.8	−36,265	−5.8

[1] Based on establishments for which data were available during 1947-61.

SOURCE: Census Bureau Time Series Project.

TABLE 4. ANALYSIS OF OUTPUT, EMPLOYMENT AND PRODUCTIVITY RELATIONSHIPS, 1957–61[1]

Industry	Percent change			D_i/H	D_p/H	D_p/D_i	GD/H	D_p/GD	R_a, H/Q	R_b, H/Q
	Employment	Output	Unit man-hours	1	2	3	4	5	6	7
A	−18	16	−29	0.18	0.16	0.93	0.21	0.78	−0.643	0.501
B	−26	−15	−12	.11	.10	.86	.28	.36	−.382	−.081
C	−18	10	−26	.18	.17	.93	.20	.85	−.540	.370
D	−18	14	−28	.18	.18	1.01	.20	.89	−.207	.445
E	−16	4	−19	.16	.11	.70	.21	.52	−.514	.307
F	−26	−24	−2	.02	.05	2.36	.26	.19	−.410	.130
G	−20	−11	−10	.09	.04	.52	.21	.19	−.249	.274
H	−31	−12	−21	.20	.14	.67	.36	.39	−.391	.440
Total	−20	7	−25	0.16	0.14	0.89	(2)	(2)	(2)	(2)

Column 1: Industry level disemployment/employment 1957 = D_i/H.
2: Plant level disemployment/employment 1957 = D_p/H.
3: Plant level disemployment/industry level disemployment = D_p/D_i.
4: Gross declines in plant employment/employment 1957 = GD/H.
5: Plant level disemployment/gross declines in plant employment = D_p/GD.
6: Correlation between percentage changes in plant output and unit man-hours = R_a, H/Q.
7: Correlation between percentage changes in plant employment and unit man-hours = R_b, H/Q.

[1] Based on establishments for which data were available during 1947-61.

(2) Not available.

TABLE 4–a. RELATIONSHIP BETWEEN CHANGES IN EMPLOYMENT AND CHANGES IN UNIT MAN–HOURS, SELECTED INDUSTRIES, 1957–61[1]

Industry	Number of establishments	Total production worker man-hours		Change in total production worker man-hours					
				Total		Associated with decrease in—			
						Unit man-hours		Output	
		1957	1961	Actual	Percent	Actual	Percent	Actual	Percent
A	23	5,939	4,895	−1,044	−17.6	−1,044	−17.6	0	0
B	20	29,946	22,302	−7,644	−25.5	−3,395	−11.3	−4,249	−14.2
C	145	176,402	143,960	−32,442	−18.4	−32,442	−18.4	0	0
D	49	145,589	119,878	−25,711	−17.7	−25,711	−17.7	0	0
E	127	54,242	45,825	−8,417	−15.5	−8,417	−15.5	0	0
F	47	31,243	23,168	−8,075	−25.8	−670	−2.1	−7,405	−23.7
G	35	63,819	51,142	−12,677	−19.9	−5,537	−8.7	−7,140	−11.2
H	30	44,596	30,924	−13,672	−30.7	−9,002	−20.2	−4,670	−10.5
Total	476	551,776	442,094	−109,682	−19.9	−86,218	−15.6	−23,464	−4.3

[1] Based on establishments for which data were available during 1947-61.

SOURCE: Census Bureau Time Series Project.

Table 5. Percent of Industry Production Worker Man-Hours (PWMH), Selected Establishments

Industry	Establishments for which 1954-61 data were available			Establishments for which 1947-61 data were available		
	Number of covered establishments	PWMH 1961 (in thousands of man-hours)	PWMH coverage 1961 (percent)	Number of covered establishments	PWMH 1947	PWMH coverage 1947 (percent)
1	49	6,999	0.59	21	4,487	0.39
2	27	25,741	.96	19	35,329	.48
3	52	19,796	.77			
4	207	162,405	.89	143	194,490	.82
5	62	123,357	.95	43	205,562	[1] 1.11
6	162	57,024	.93	117	52,080	.79
7	230	757,920	.99			
8	29	16,195	.96			
9	59	24,160	.79			
10	55	29,478	.87			
11	136	62,539	.83			
12	66	54,827	.87			
13	71	67,809	.79			
14	42	8,168	.30			
15	91	43,474	.73	46	32,064	.48
16	43	56,713	.90	33	70,208	.48
17	46	39,705	.88	23	44,827	.77
Total	1,427	1,556,310		445	639,047	

[1] Greater than 100 percent because some plants are included in this study which were classified in Industry 3099, Rubber Not Elsewhere Classified, in 1947.

Table 6. Coefficients of Correlation Between Selected Variables Based on Percent Change 1957 to 1961[1]

Industry	Coefficient of correlation between unit man-hour requirements and:			
	Production[2]		Production worker man-hours	
	r	s_r	r	s_r
1	−0.625	0.092	0.356	0.132
2	−.499	.150	−.256	.187
3	−.420	.123	.306	.135
4	−.642	.152	.540	.183
5	−.685	.116	.144	.214
6	−.532	.052	.399	.061
7	−.164	.132	.507	.101
8	−.525	.060	.297	.075
9	−.384	.059	.209	.066
10	−.647	.116	−.221	.190
11	−.285	.123	.369	.115
12	.012	.139	.510	.103
13	−0.320	0.079	0.098	0.088
14	−.758	.095	.288	.205
15	−.764	.104	.017	.250
16	−.659	.146	.050	.258
17	−.396	.109	.309	.117
18	−.151	.127	.531	.094
19	−.017	.167	.621	.102
20	−.366	.092	.172	.103
21	−.187	.279	.139	.283
22	−.288	.147	.219	.152
23	−.314	.146	.446	.130
25 industries combined[3]	−.463	.021	.208	.025

r=Coefficient of correlation.
s_r=Standard error of r.

[1] Establishments for which data were available during 1954-61.

[2] Deflated adjusted gross production.

[3] Includes data for two industries for which data are not shown separately.

Source: Annual Survey of Manufactures Time Series Records for 25 industries for the years 1954-61.

Table 7. Coefficients of Correlation Between Selected Variables Based on Percent Change 1947 to 1961[1]

Industry	Coefficient of correlation between unit man-hour requirements and:			
	Production[2]		Production worker man-hours	
	r	s_r	r	s_r
1	−0.344	0.164	0.402	0.156
2	−.157	.230	.284	.217
3	−.671	.137	.328	.223
4	−.228	.080	.524	.062
5	−.306	.135	.170	.145
6	−.511	.067	.425	.074
7	−0.413	0.207	0.466	0.196
8	−.667	.168	−.091	.299
9	−.251	.115	.206	.118
10	−.213	.177	.080	.185
11	−.024	.218	.108	.216
15 industries combined	(3)	(3)	(3)	(3)

r=Coefficient of correlation.
s_r=Standard error of r.

[1] Establishments for which data were available during 1947-61.

[2] Deflated adjusted gross production.

[3] Not available.

Source: Annual Survey of Manufactures Time Series records for 15 industries for the years 1947-61.

TABLE 8. COEFFICIENTS OF CORRELATION BETWEEN SELECTED VARIABLES BASED ON PERCENT CHANGE 1947 TO 1957[1]

Industry	Coefficient of correlation between unit man-hour requirements and:				Industry	Coefficient of correlation between unit man-hour requirements and:			
	Production[2]		Production worker man-hours			Production[2]		Production worker man-hours	
	r	s_r	r	s_r		r	s_r	r	s_r
1	−0.403	0.153	0.340	0.161	7	−0.061	0.249	0.464	0.196
2	−.288	.216	.042	.235	8	−.665	.168	.337	.267
3	−.461	.186	.491	.179	9	−.377	.106	.072	.122
4	−.303	.076	.411	.069	10	−.389	.155	.072	.182
5	−.287	.137	.237	.141	11	−.271	.202	−.039	.218
6	−.503	.067	.388	.076	15 industries combined	(3)	(3)	(3)	(3)

r=Coefficient of correlation.
s_r=Standard error of r.

[1] Establishments for which data were available during 1947–61.

[2] Deflated adjusted gross production.

[3] Not available.

SOURCE: Annual Survey of Manufactures Time Series records for 15 industries for the years 1947–61.

TABLE 9. COEFFICIENTS OF CORRELATION BETWEEN SELECTED VARIABLES BASED ON PERCENT CHANGE 1953 TO 1959[1]

Industry	Coefficient of correlation between unit man-hour requirements and:				Industry	Coefficient of correlation between unit man-hour requirements and:			
	Production[2]		Production worker man-hours			Production[2]		Production worker man-hours	
	r	s_r	r	s_r		r	s_r	r	s_r
1	−0.302	0.175	0.639	0.114	7	−0.727	0.111	0.098	0.233
2	−0.447	0.200	−0.022	0.250	8	−0.580	0.184	0.050	0.277
3	−0.630	0.135	0.014	0.224	9	−0.560	0.093	−0.008	0.136
4	−0.422	0.072	0.415	0.072	10	−0.556	0.120	−0.414	0.144
5	−0.312	0.136	0.246	0.142	11	−0.272	0.197	0.209	0.204
6	−0.480	0.073	0.423	0.078	15 industries combined	(3)	(3)	(3)	(3)

r=Coefficient of correlation.
s_r=Standard error of r.

[1] Establishments for which data were available during 1947–61.

[2] Deflated adjusted gross production.

[3] Not available.

SOURCE: Annual Survey of Manufactures Time Series records for 15 industries for the years 1947–61.

TABLE 10. COEFFICIENTS OF CORRELATION BETWEEN SELECTED VARIABLES BASED ON PERCENT CHANGE 1957 TO 1961[1]

Industry	Coefficient of correlation between unit man-hour requirements and:				Industry	Coefficient of correlation between unit man-hour requirements and:			
	Production[2]		Production worker man-hours			Production[2]		Production worker man-hours	
	r	s_r	r	s_r		r	s_r	r	s_r
1	−0.643	0.094	0.501	0.120	7	−0.766	0.095	0.278	0.212
2	−.382	.182	−.081	.212	8	−.844	.077	.057	.266
3	−.738	.105	.064	.228	9	−.410	.094	.130	.111
4	−.540	.055	.370	.067	10	−.249	.154	.274	.152
5	−.207	.134	.445	.112	11	−.391	.150	.440	.143
6	−.514	.063	.307	.078	15 industries combined	(3)	(3)	(3)	(3)

r=Coefficient of correlation.
s_r=Standard error of r.

[1] Establishments for which data were available during 1947–61.

[2] Deflated adjusted gross production.

[3] Not available.

SOURCE: Annual Survey of Manufactures Time Series records for 15 industries for the years 1947–61.

AN INVESTIGATION OF THE RATE OF DEVELOPMENT AND DIFFUSION OF TECHNOLOGY IN OUR MODERN INDUSTRIAL SOCIETY

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The Rate of Development and Diffusion of Technology

1. Introduction

World War II initiated a new era in science and technology. For the first time in history, the industrial nations of the world—the United States, England, Germany, Russia, and Japan—spent substantial public funds to accelerate technological development. Although the primary objective of these research efforts was the development of new military weapons, such as guided missiles and the atomic bomb, they also produced a number of important innovations which formed the basis for a host of new industrial and consumer products after the war. Many of these products—radar, microwave communications, jet aircraft, electronic computers—have become an important part of our modern industrial and consumer way of life.

In the United States alone, expenditures for technological research and development during World War II amounted to more than $4 billion, the major portion of which was provided by the Federal Government. After the end of World War II, Government research and development expenditures for military and defense applications declined, but they increased significantly again during the Korean war. Government-supported research and development has continued to increase since that time as the country's military and defense needs required new concepts in weapon systems built upon advances in science and technology. More recently, the Federal Government has provided a new impetus to public support of research and development in space exploration. As a result, Federal Government expenditures for research and development increased from $1.6 billion in 1950 to an estimated $15 billion in 1965.

A second impetus to this country's growing technological orientation also emerged from World War II, the result of the realization by business and industry that new and profitable competitive advantages could be gained from technology through the development of new products, processes, and services. One outstanding example of the potential of technological innovation is the television industry which, while virtually nonexistent prior to World War II, in the subsequent 20 years contributed more than $16 billion to our economic output. Another new industry that has emerged from technology is electronic data processing. Since the basic discovery in this field was made 20 years ago, the industry has grown rapidly to where its output was $1.4 billion in 1964. The net result of the growing awareness of business and industry in the competitive advantages of technological innovation is an increase in industrial expenditures for research and development from $1.2 billion in 1950 to an estimated $5.5 billion in 1965.

This combination of public and private investment in technological advancement has created a vast reservoir of scientific and technical knowledge which has fostered new industrial and consumer products, new business organizations, and entire new industries. It has also generally become an important factor in the continued growth of our industrial economy. However, the impact of technology is not limited only to business and industry. Technological innovations are creating new job opportunities, making obsolete existing skills, and creating demands for new skills; they are affecting what we eat, what we buy, how we spend our leisure time, and even what we teach our children. In total, they are affecting virtually every facet of our way of life.

Technological discovery and development are likely to accelerate in the future as public and private investment in research and development continues to increase. Further impetus to technological change is provided as business organizations establish long-range planning groups whose primary function is to identify innovations in embryonic stages. Their objective is to channel company funds and efforts into the most promising areas to exploit the competitive advantages of innovations more rapidly and effectively.

Despite the fact that technological advancement and the rate at which technology is changing increasingly affects our economy and way of life, very little factual information is available on the process and factors influencing the rate of change. Yet it is important that we know more about these factors because they often result in significant social and economic changes, some of which may be less than desirable for certain individuals, business organizations, communities, and even entire geographical areas. The objective of this study is to investigate the entire process of technological discovery, development, and diffusion, and to answer the following questions:

> How much time is required to translate a major technological innovation from the laboratory stage to the point where it becomes a commercial product or process?
>
> What period of time is required for a major technological innovation to attain a level where it can be said to have a significant economic and social impact?
>
> Have these time intervals been decreasing in recent years, and are these changes of particular significance?
>
> What is the impact of the Federal Government's expenditures on research and development for military and defense programs?
>
> What other external factors appear to influence the rate of development and diffusion of technology?

To provide these answers, this study investigated 21 major technological innovations introduced during the last 60 to 70 years that have had a significant social and economic impact. The chronology of discovery and development of each of these innovations was established and compared to determine what changes have occurred in the rate of technological development during the last 60 to 70 years and to determine what effects such factors as Government research and development expenditures have on this rate of development. Similarly, the economic growth (measured in relation to gross national product) of each of these innovations was determined and compared to evaluate the changes that have occurred in the rate of diffusion of technology. A more complete description of the methodology and criteria used in these determinations is contained in section 4 of this report.

The report presents the basic methodology used in this investigation, the results of the analysis of the rate of development and diffusion, and the conclusions that were derived from this analysis. The appendix presents a brief history of the discovery, development, and economic growth of each of these technological innovations, including the basic data that were used in the analysis.

2. Summary

Technology is only one of many interrelated forces that continually act upon our economy and society. However, in comparison to most of these forces, technology has a more dynamic nature and changes resulting from it generally occur at a rapid rate. That the television industry could attain a level of output in excess of $1 billion and become an intimate part of the lives of our population within a period of 5 years provides a dramatic illustration of technology's dynamic potential.

During the last 20 years, the rapid increase in Federal Government expenditures for research and development in the defense and space programs has combined with the growing interest by business and industry in technology as a source of competitive advantage to increase further the role of technology as an agent of change. New scientific and technical knowledge has already resulted in the development of thousands of new industrial and consumer products, fostered the establishment and growth of hundreds of new business organizations, created entire new industries, and generally contributed substantially to the overall growth of our economy. This new knowledge has resulted in the creation of new job opportunities and the elimination of others; it has created demands for new skills and made others obsolete; it has affected what we eat, what we buy, how we spend our leisure, what we teach our children—in total, it has affected every facet of our way of life.

In the past, the natural forces within our economy and society have been left to accommodate to technological changes. However, growing public and private investment in research and development have so rapidly increased our scientific and technical resources that there is growing concern regarding the ability of natural forces to continue to cope with the resulting changes. Yet very little factual information is available concerning the rate of technological change and factors that influence it.

Economists have for some years been attempting to measure the rate of technological change and its impact on our economy and society. But because their measurements have been primarily concerned with the overall economic effects of technology, they provide very little insight into the rate at which technological changes occur in individual segments of our economy. From past experience, it is evident that the rate of technological change varies considerably from one industry to another; certainly, it has been far greater in the electronics and chemical industries than in the furniture and food industries.

The rate of technological change is the product of two independent factors—the rate at which innovations are introduced into the economy, and the rate at which each diffuses through the economy, bringing about changes. Unfortunately, there is no reliable method by which these rates can be measured directly, just as there is none to measure the economic impact of technology. Three indirect methods have been used to measure changes in the rate at which innovations are being introduced into the economy—expenditures for research and development, the number of scientists in research and development, and the number of patents issued. These measures indicate that—

> total expenditures for research and development increased slightly more than 300 percent in the last 10 years, from $5.7 billion in 1954 to an estimated $17.4 billion in 1963;
>
> the number of scientists and engineers engaged in research and development in industry increased slightly more than 200 percent in that same period, from 164,000 in 1954 to an estimated 339,400 in 1963;
>
> the number of patents issued increased from 379,000 in the 5-year period from 1951 to 1955, to 457,000 in the period from 1960 to 1964.

Even with the limitations of these indicators, it can be concluded with a reasonable degree of certainty that the rate at which technological innovations are being introduced into our economy has increased significantly during the last 10 years. However, this increase is cause for concern only if the ability of our economy to accommodate to the impact of changes is overwhelmed.

The rate at which technology is diffused through our economy is the more critical aspect of the question of acceleration in the rate of technological change. Its importance lies in its indication of the amount of time available for our economy and society to react to technological changes.

The results of this study indicate that every step in the process of technological development and diffusion has accelerated during this period. More specifically:

> the average lapsed time between initial discovery of a new technological innovation and the recognition of its commercial potential decreased from 30 years for technological innovations introduced during the early part of this century (1880–1919), to 16 years for innovations introduced during the post-World War I period, and to 9 years for the post-World War II period;
>
> the time required to translate a basic technical discovery into a commercial product or process decreased from 7 to 5 years during the 60- to 70-year time period investigated;
>
> the rate of diffusion (as measured by economic growth) for technological innovations introduced during the post-World War II period was approximately twice that for post-World War I innovations, and four times the rate for innovations introduced during the early part of this century.

These investigations also indicate that the rate of development and diffusion is:

> nearly twice as fast for technological innovations with consumer applications as for those with industrial applications;
>
> somewhat faster for innovations developed with Federal Government funding than for those developed by private industry, but not as much as might be expected;
>
> somewhat faster for innovations introduced into an existing industry as compared to those that required the creation of an entire new industry.

This study has provided an insight essential to the establishment of a national policy regarding the effects of technological change. It demonstrated that the rate of development and diffusion of technology is indeed accelerating, but that the lapsed time required for commercial development and diffusion is such that an "early warning system" to identify potentially important technological innovations in early stages of research and development is not necessary. It can be stated with reasonable confidence that those technological innovations which will have a significant impact on our economy and society during the next 5 years have already been introduced as commercial products, and those technological innovations that will have a significant social and economic impact during the 1970–75 period are now in a readily identifiable state of commercial development.

Therefore, the problem of coping with technological change is not one of anticipating technological innovations far in advance of their commercial development; it is, rather, in adequately identifying the direct and indirect impact of innovations now in existence. Thus the Federal Government should emulate private business and industry's efforts to anticipate the effects of new technological developments. Companies have learned that insight into the direct and indirect effects of technology cannot be gained on a part-time basis and simply by obtaining a consensus of opinion. All too often, individuals within a field are unaware of outside developments that will have an important impact on their industry, and outsiders who have no perspective by which to gage the practical difficulties often make totally unrealistic estimates of the rate of technological change. Therefore, business and industry have discovered that accurate interpretation and forecasting of technological change require unique capabilities and an organization that devotes full time to these activities. The Federal Government also needs such a staff organization to monitor and analyze the impact of technology. Furthermore, efforts should not be limited to forecasting effects on the labor force but should also be concerned with the indirect effects of technology on such areas as transportation policy, utility regulation, education and training programs, antitrust activities, and other fields of Federal, State, and local government concern.

Study findings also provide a crude but useful tool for monitoring technological innovations. For example, the rate of diffusion for a major technological innovation with consumer applications in existing industry, such as television and civilian jet aircraft, can be expected to be very rapid and should be monitored very closely. On the other hand, a major technological innovation that will foster the creation of a new area of industrial activity (e.g., the laser) can be expected to have a relatively slow rate of diffusion and therefore would not have to be monitored as carefully. Similarly, other factors, such as the source of development funds, could be incorporated into any assessment of the rate of development and diffusion to determine the changes that will accompany a given technological innovation and the extent to which it will need to be monitored.

3. Understanding the Process of Technological Innovation

The traditional "Horatio Alger" of technological innovation is a young man who, while working late one night in a homemade laboratory in his basement, accidentally makes a major new discovery that is quickly adopted by industry. Part of this story, with some variations, has happened in life a number of times in the past (e.g., Bell with the telephone, Morse with the telegraph, and Goodyear with rubber), and probably is happening today, although to a much lesser extent than during the 19th and early part of this century. However, the portion dealing with the commercial development and exploitation of a new discovery is largely a myth in our modern industrial society.

Although it is possible for a technological innovation to be discovered by an individual and achieve widespread application by word-of-mouth or by a technique that does not involve a deliberate investment of capital for commercial development and exploitation, the rate at which it is diffused would be so slow that the ensuing changes would not be a matter of concern. In our modern society, a major technological innovation is characteristically introduced by a company or group of companies which recognize the potential commercial application of a technological innovation (discovered by themselves or others) and invest considerable effort and funds in developing it commercially and exploiting its applications. This type of success story can be found in the history of such innovations as synthetic fibers, radio and television, electronic computers, and frozen foods. It is of particular concern because changes resulting from this type of technological innovation can occur so quickly that natural economic and social forces may not be able to react and adjust effectively, thereby creating problems in our society.

In order to anticipate, identify, and cope with the problems created by technology, it is necessary to know more about the process of technological innovation, the factors that influence the rate at which innovations diffuse into our economy, and the methods by which this diffusion can be measured. This section is concerned with providing some insight and understanding into these problems.

The Economics of Technological Innovation. While a new technological innovation may be discovered without the expenditure of funds, its conversion into a product and its commercial exploitation invariably requires such expenditures. The amount is determined by the technical difficulties that arise during commercial development, capital investment requirements for plant and facilities, and costs in developing applications. For example, Du Pont estimates that it invested $2 million on research and development of the first synthetic fiber (Nylon) but because of the complexity of its synthetic leather product (Corfam), it took $25 million to develop this new product. Because the willingness of companies and private individuals to invest in technology has an important effect on the rate of development and diffusion, it is important to know something about the economics of development and diffusion.

Fundamentally, most technological innovations are introduced into our industrial and consumer economy because of the very nature of our free enterprise system. They provide an opportunity for competitive advantage in the form of increased sales of existing products, lower production costs, or new or better products and/or services, all of which eventually (and hopefully) translate into increased profits. Therefore, the greater the potential profit from a technological innovation in relationship to the amount of investment, the more willing and anxious a company is to invest in it. This is one apparent reason why technological innovations in consumer applications have a faster rate of diffusion than those in industrial applications—potential profits are usually much greater in the consumer field because of the size of the market.

Another factor entering into the economic equation for technological innovation is the element of risk. Since there is usually a degree of uncertainty both in the technical aspects of commercial development and the profit potential of commercial exploitation, the invester in a technological innovation must balance this risk against the total amount of funds invested and the expected return on investment. The extent of the risk can be reduced to some extent by decreasing the rate at which the investment is made. This lengthens the time period for commercial development and decreases the rate of diffusion, but it also provides a greater time perspective in which the merits of the investment can be evaluated.

Still another way for a company or even an entire industry to reduce the risk of investing in a new technological innovation is to have the Federal Government assume all or a part of the risk. This condition is found in most technological innovations initially intended for military and defense applications. The Federal Government can assume risk by financing research and development, underwriting the market, subsidizing production costs, and even financing the construction of manufacturing facilities. The Federal Government has, in fact, played a significant role in reducing the risk of investing in a number of important technological innovations in the last few years, and therefore is becoming more important in determining the rate of development and diffusion of technology.

The problem of assessing the economic potential of technological innovation has become such an important consideration in business and industry that many companies are establishing separate groups within their organization with the sole function of evaluating capital investment requirements, profit potential, and inherent risks involved in technological innovations. If these corporate and product planning groups are successful in doing a better job, the effect should be to accelerate the rate of development and diffusion of technology and decrease the number of technological innovations (particularly unsuccessful ones) introduced each year.

The Measurement of Technological Innovation. Technology is one of the major forces that continually act and interact upon our economy. Some of these forces, particularly social and economic ones, tend to occur slowly and on such a broad scale that they are difficult to control. Technological changes are usually more dynamic because they tend to occur at a much faster rate and are, to some extent, controllable by the amount of funds invested in their exploitation. The television industry's ability to attain a level of output of $1 billion in a period of 5 years is certainly an excellent example of the dynamic nature of technological innovation.

Because of this dynamism, economists for some years now have been attempting to measure the impact of technological innovation on our society. To a large extent, these attempts have been unsuccessful because the effects of technology cannot be measured in economic terms directly, but must be imputed from other economic measurements. One economist, Edward Denison,[1] has measured the contribution of technology to the growth of our economy by starting with changes in the real gross national product during the last 50 years and subtracting the changes caused by other economic factors—hours of labor, capital investment, working population, and others, with the remainder representing the contribution of technology. Another more widely known method of measuring an aspect of the impact of technology on our economy uses changes in the productivity of labor.[2]

One difficulty of these and other methods lies in their concern with the overall effect of technological innovation on the economy. Yet past experience shows that the effects of technological change vary considerably from industry to industry. Certainly, the contribution of technology to the growth of the electronics and chemical industries has been far greater than the furniture and food industries. Because the problems created by technological innovations are much more acute when the changes occur in a few years rather than over a generation or two, overall measures of the impact of technology do not truly reflect the magnitude of the problems that can arise from technological innovation.

Another major problem in measuring technological change is the difficulty in distinguishing between the two basic components that together determine the change—the number of technological innovations introduced, and their rate of diffusion. As with overall technological changes, no reliable techniques by which these factors can be measured directly exist. Attempts have been made to measure changes in the quantity of technological innovations introduced by such indirect factors as changes in research and development expenditures, the number of patents issued, or the number of scientists and engineers engaged in research and development activities. However, it is highly doubtful if any of these measures accurately reflect the true changes in the number of technological innovations introduced each year, and certainly they do not provide any indication if more significant technological innovations are being introduced now than in the past.

The rate of development and diffusion of technology as a factor determining the overall effect of technological change is the primary concern of this investigation. This rate is critical because it determines whether sufficient time is available for natural forces within our economy and society to adjust to changes accompanying innovations. If this rate is accelerating so that the adjustment period is too short, then methods for anticipating the impact of technological changes and instituting corrective measures may have to be developed.

4. The Rate of Development and Diffusion of Technology

Technological innovation appears to be a basic characteristic of our society. During the last 25 years, the U.S. Patent Office has issued more than 1 million patents, ranging in complexity from plastic zippers to the continuous casting of steel. Even these patent statistics understate the amount of technological innovation in this country because many innovations, particularly in the field of manufacturing processes, are not patented, either because they involve new applications of existing technology and are not patentable or because the patent application itself would reveal proprietary information that would be of considerable value to others. Some of these innovations have been successfully exploited as new commercial products, processes, or services; others are successful only in the eyes of the inventor.

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[1] Edward F. Denison, *Source of Economic Growth in the United States*, Committee for Economic Development, New York, 1962.

[2] *Trends in Output Per Man-Hour in the Private Economy*, Bureau of Labor Statistics, Washington, D.C.

Periodically throughout history, some technological innovations have been developed which have a very significant social and economic impact. They create a major new industry, displace or make obsolescent existing products, provide an important new medium of communication, or even alter the way we live. Such technological innovations as the steam engine, line-casting machine, telephone and telegraph, electric light, and internal-combustion engine fall into this category, as do such more recent innovations as radio and television, the airplane, synthetic resins, the vacuum tube, the automobile, and synthetic fibers. Some recent technological innovations which appear to meet this criterion include electronic computers, semiconductors and integrated circuits, synthetic leather, numerical control, and atomic power generation.

Selection of Innovations. The diverse nature of technological innovation created a basic problem in this study concerning the selection of innovations to be investigated. Because of the Commission's concern with the impact of technological change, this investigation was limited to innovations that have caused significant changes in our economy and society. Thus, technological innovations were chosen that have created, or are expected to create, entire new industries, displaced existing products and processes, changed training and skill requirements of workers, or made an important contribution to society.

Another more practical reason for restricting this investigation to major technological innovations was the method employed to measure the rate of diffusion of technology. Since this measurement was based on economic growth, it was necessary to select innovations of such magnitude and importance that reasonably reliable economic data were available throughout the entire history of the innovations, a requirement which imposed a further restriction on the selection. Because adequate detailed economic data are virtually unavailable prior to the start of this century, selection had to be confined to technological innovations that were introduced into our economy during the last 60 to 70 years.

A preliminary investigation indicated that three other factors might also have an important influence on the rate of development and diffusion of technological innovations, and therefore should be considered in selection. These factors are:

1. *The type of market application.* It is reasonable to expect that substantial differences exist between the rate of development and diffusion for innovations with consumer applications and those with industrial or commercial applications. Industrial innovations normally have demonstrable economic advantages (e.g., lower costs, better quality, or increased sales) which considerably influence the rate at which industry will adopt new technology—the greater the incentive, the more rapidly it will be introduced. For innovations with consumer applications, economic considerations are seldom important, except to the extent that costs limit the size of the market. The rate of introduction generally depends upon the creation of a consumer demand and acceptance. On the other hand, most consumer markets are so much larger than industrial markets that major new consumer innovations are likely to have a much greater economic and social impact than those with industrial applications.

2. *The source of development funds.* In recent years a number of major technological innovations have resulted from research and development efforts funded by the Federal Government for military and space programs. For example, semiconductors, numerical control, electronic computers, and nuclear power generation, as well as a host of other less significant innovations, owe their development to Federal support. In contrast, the entire development and market exploitation of such technological innovations as synthetic fibers and synthetic leather were completely under the control of one company. Between these two extremes lie varying combinations of public and private participations in funding technological development.

One other important aspect of the source of development funding is its effect on the rate of diffusion of a new technology. Most innovations developed by private companies have a proprietary status protected by our patent system, whereas innovations developed under Government funding are often made freely available to any interested company without licensing or royalty payments. The availability of patent protection would seem to be an incentive for a company to develop new technological innovations, but this would also probably retard the rate of diffusion since the number of companies, and, therefore, the amount of funds expended on commercial exploitation, would be limited. A primary reason for the very rapid growth of the semiconductor field was the availability of basic patents. Because the source of development funding appeared to be significant in considering the rate of development and diffusion of technology, an attempt was made to reflect this factor in the selection of innovations to be studied.

3. *Intraindustry innovations.* In reviewing a list of major technological innovations introduced into various industries during the last 60 to 70 years, it was evident that certain fields have experienced more than one major innovation during the period. For example, vacuum tubes, semiconductors, and integrated circuits were introduced into electronic circuitry over a span of 40 years, and each has had or will have an important impact on the electronics industry. Similarly, frozen foods and freeze-dried foods are important developments in food processing introduced during this period, as are antibiotics and vitamins in the drug field. By selecting several intraindustry innovations, it was felt that some of the problems of comparing innovations from one field to another could be reduced, and perhaps a better measure of changes in the rate of development and diffusion of technology could be obtained.

It would have been desirable to select a large number of technological innovations in each category to provide sufficient opportunity to investigate independently the influence of each factor on the rate of development and diffusion of technology. However, the requirement for detailed economic data severely restricted the number of innovations that could be analyzed. Exhibit 1 lists the 20 technological innovations finally selected along with some important characteristics of each—date of commercial introduction, current level of output, nature of market application, primary source of development funds, and the type of innovation. Although 21 technological innovations were initially selected for investigation in this study (see the appendix to this report), one of these innovations, magnesium, was excluded from this analysis because it was felt that magnesium's history of development and economic growth (due to direct competition from aluminum) was inconsistent with that of the 20 other innovations.

Although selection was made on the basis of the rather arbitrary criteria discussed above, the list appears to include most of the technological innovations that have had a major impact on our economy and society during this century. The selection also provides a reasonable balance between other factors influencing the rate of development and diffusion of technology. However, because of the limited number of innovations involved, these factors are intermixed to such an extent that considerable judgment had to be used in assessing the importance of each.

Measuring the Rate of Development and Diffusion. Perhaps the most difficult problem in this entire undertaking was the establishment of a yardstick to measure the rate of development and diffusion for such diverse technological innovations as electronic computers, frozen foods, synthetic fibers, and nuclear power generation. The most obvious yardstick is "time," which requires the definition of certain critical reference points within the entire process of technological development and diffusion in order that lapsed time can be measured and compared in a reasonably objective manner.

After examining the chronology of discovery, development, and diffusion for a number of technological innovations, four steps in the process were identified:

1. *Basic research and investigation.* The period of basic research and investigation can best be defined as the time when knowledge is generated for knowledge's sake. In most instances, the beginning of this period, when the original idea occurs, is impossible to ascertain for it may be traced as far back as Greek mythology (the airplane) or early science fiction (television). Therefore, no attempt was made to measure this period other

EXHIBIT 1. CHARACTERISTICS OF TECHNOLOGICAL INNOVATIONS STUDIED IN THIS INVESTIGATION

Technological innovation	Date of commercial introduction	Current output (millions)	Type of market application	Type of innovation	Primary impetus to development
Aluminum	1892	[2] 1,211	Industrial	Primary	Industry.
Motor vehicle transportation	1895	[2] 17,955	Consumer	do	Do.
Synthetic resins	1910	[2] 2,310	Industrial	do	Do.
Air transportation	1911	[1] 19,131	Consumer	do	Government.
Electronic vacuum tubes	1920	[2] 688	Consumer/industrial	do	Industry.
Radio broadcasting	1922	[1] 1,042	Consumer	do	Do.
Frozen foods	1925	[2] 4,381	do	Secondary	Do.
Vitamins	1937	[1] 91	do	Primary	Do.
Synthetic fibers	1939	[2] 1,730	do	Secondary	Do.
Synthetic rubber	1940	[2] 807	do	do	Government.
Antibiotics	1940	[1] 470	do	Primary	Industry.
Television broadcasting	1945	[1] 2,683	do	Secondary	Do.
Titanium	1950	[2] 21	Industrial	do	Government.
Electronic computers	1950	[2] 1,400	do	Primary	Do.
Semiconductors	1951	[2] 650	do	Secondary	Do.
Numerical control	1955	[1] 84	do	do	Do.
Nuclear power generation	1957	[2] 54	Consumer	do	Do.
Freeze-dried foods	1961	[2] 34	do	do	Do.
Integrated circuits	1961	[2] 52	Industrial	do	Do.
Synthetic leather	1964	Unknown	Consumer	do	Industry.

[1] 1963 data. [2] 1964 data.

than to note some of the more outstanding fundamental research and experimentation that preceded the discovery of each innovation.

2. *Incubation period.* The incubation period begins when technical feasibility of an innovation is established, and ends when its commercial potential becomes evident and efforts are made to convert it into a commercial product or process. The existence of an incubation period is in direct conflict with the widely held concept that a basic technological discovery is immediately followed by a hectic period of development as individuals and companies rush to convert the innovation into a commercial product or process. Although this has happened with several recent innovations (e.g., semiconductors and lasers), the investigations indicated that this is the exception rather than the rule. For most innovations, a period of time lapses (sometimes quite long), when very little progress is made or even attempted to convert the discovery into a commercial product or process.

There appears to be no single reason for this incubation period; rather, it results from technical, economic, and/or market factors which influence the assessment of the commercial potential of an innovation. For example:

> Radio was originally viewed as an adjunct to the telephone and telegraph as a medium of private communication; its potential role as a medium of mass communication through broadcasting was not recognized until several years after it was in use commercially for private communication purposes.
>
> The process for manufacturing synthetic rubber was available for more than 20 years before commercial development was started. The commercial potential of the process did not become evident until technical advances had been made in the production of required raw materials.
>
> Frozen foods had to await the creation of an economic climate in which the consumer was willing to pay a premium for the convenience of these foods.
>
> The commercial potential of the vacuum tube did not become evident for 8 years after its initial discovery, until research on the nature of electron flow in a high vacuum was successful.

The incubation period could be of particular importance to changes in the rate of development and diffusion of technology because the period could be shortened significantly in the future by industry's long-range and product planning activities.

3. *Commercial development.* Commercial development begins with the establishment or recognition of the commercial potential of a technological innovation. It is normally characterized by a decision to undertake development to resolve the remaining technical and economic obstacles to commercial applications of an innovation. This may be undertaken by a company, the Federal Government, or even a private individual, but it is always a directed effort to reach a reasonably well-defined commercial objective. In addition, this period includes the time and effort required to develop the required production processes and equipment. The commercial development period ends when the innovation is introduced as a commercial product or process.

4. *Commercial growth* (*diffusion*). The diffusion of technological innovations into consumer and industrial applications is a complex process of vital interest to this study since it determines the rate at which the changes brought about by technology will affect our economy. The commercial growth cycle followed by innovations typically involves an interplay of technical and economic factors—new applications increase production by lowering costs, and thereby enlarging the scope of applications. Eventually, the original innovation is displaced by newer innovations or by economic and social changes.

Because the process of diffusion is a continual progression of events that is almost impossible to define chronologically, it was necessary to use economic growth as a measure of the rate of diffusion. While economic growth may not be the most ideal measure, since it is admittedly an indirect indicator, it does provide a common denominator by which the rate of diffusion of one technological innovations can be compared with another. Furthermore, economic measures of the diffusion of innovations have a very close relationship with one important aspect of technological change—the impact on the labor force.

If the economics of technological innovations are traced through their production process—raw materials used, electrical power, gas, and other utilities required, and other factors contributing to production—the total output of these innovations at some point in the process is eventually translated into wages or return on invested capital. Since wages, either direct or indirect, probably comprise the largest proportion of the total, an innovation's economic growth probably provides a reasonably good measure of its overall effect on the labor force.

A basic drawback to the use of economic criteria as a measure of the rate of diffusion is their limited scope. Although economic data are available for such direct measures as value of manufacturers' output and revenues from services (for example, airline revenues), similar data for activities indirectly connected with the innovation generally are not available in the detail necessary. For example, in this investigation, the output of the radio and television industries was measured by combining the value of output for radio and television set manufacturing with revenues from radio and television broadcasting. However, this does not take into account the economic contribution of television and radio in supporting retail appliance stores and service shops. Similarly, the measurement of output of the electronic computer industry does not include the value of services supplied by data processing service centers scattered throughout the country and the value of business forms consumed by these computers. Because of this deficiency, economic measures used probably represent only 25 to 50 percent of the true contribution of these innovations to our economy.

The method employed to measure the rate of diffusion involved the establishment of a series of economic benchmarks, with the lapsed time required for innovations to attain each benchmark determined and compared. Two different sets of benchmarks were used—one, a relative economic measure, based on percent of gross national product (i.e., 0.02, 0.05, 0.10, 0.15, 0.25, 0.50 percent, etc.) and the other, an absolute economic measure, based on the dollar value of output (i.e., $50 million, $100 million, $250 million, $500 million, etc.) converted to constant dollars based on the 1957–59 Index of Wholesale Prices.

Of these, the percent of GNP is probably the more valid method of measuring the rate of diffusion over the entire period under investigation since one of the primary considerations in this investigation is the effect of technological change on employment opportunities. Thus, the GNP-based measurement more accurately reflects this contribution, since average weekly earnings have grown nearly as rapidly during the period under investigation as gross national product. (GNP in 1920 was 16 percent of 1963 GNP, whereas 1920 average weekly earnings were 26 percent of those in 1963.) Therefore, a technological innovation that attained a level of output of 0.25 percent in 1925 contributed roughly as many new employment opportunities as another innovation that attained a similar level in 1963. Absolute levels of output are not as reliable a measure of the rate of diffusion throughout the entire period under investigation. However, it is much easier to apply than the GNP-based measurement and could be used as a reasonably good indicator over a limited time span.

The method employed to measure the rate of development and diffusion of technology in this study is relatively crude and unsophisticated. A number of more sophisticated methods, particularly to measure economic growth, could be utilized; for example, mathematical curve analysis and compounded rate of growth. However, after examining both the data and the chronology of the selected innovations, the inescapable conclusion is that the inaccuracies and assumptions inherent in this type of investigation simply could not justify the use of more precise measurement techniques. The effects of three wars (World War I, World War II, and the Korean war) and the defense and space programs are so complex that sophisticated measurement techniques simply were not warranted.

The Rate of Development of Technology. As indicated above, two distinct steps occur in the process of technological development after the technical feasibility of an innovation has been established:

1. A period ensues when little or nothing of a concrete nature occurs because although technical feasibility has been established, a number of missing elements must be supplied before the commercial potential becomes evident.
2. Once the commercial potential has been recognized, a period of commercial development ensues when a directed effort is made to convert the basic technology into a technically and economically feasible product or process.

Exhibit 2 shows the incubation period and commerical development period for each of the technological innovations studied and the date when commercial development work was initiated. As the chart indicates, there is a large variation, particularly in the incubation period. For example, frozen foods had an incubation period of 74 years, whereas the incubation period for integrated circuits was only 2 years. A similar variation exists for the commercial development period, ranging from 14 years for titanium and synthetic leather to only 1 year for antibiotics. For these 20 innovations, the average incubation period was 19 years, and for commercial development, 7 years. These averages are not particularly important to this investigation except that they emphasize that the time required for a major technical discovery to

EXHIBIT 2. RATE OF DEVELOPMENT FOR SELECTED TECHNOLOGICAL INNOVATIONS

Technological innovation	Start of commercial development	Lapsed time (years)		
		Incubation period	Commercial development	Total development
Aluminum	1886	31	6	37
Motor vehicle transportation	1891	23	4	27
Air transportation	1903	6	8	14
Synthetic resins	1907	49	3	52
Radio broadcasting	1913	17	9	26
Electronic vacuum tubes	1914	7	6	13
Frozen foods	1916	74	9	83
Vitamins	1926	13	11	24
Synthetic rubber	1929	20	11	31
Television broadcasting	1933	22	12	34
Synthetic fibers	1936	6	3	9
Titanium	1936	26	14	40
Antibiotics	1939	11	1	12
Electronic computers	1944	15	6	21
Semiconductors	1948	7	3	10
Numerical control	1948	18	7	25
Synthetic leather	1950	12	14	26
Nuclear power generation	1954	11	3	14
Freeze-dried foods	1955	4	6	10
Integrated circuits	1958	2	3	5
Average	----------	19	7	26

be converted into a useful commercial product or process (an average of 26 years) is far longer than generally recognized.

To assess changes in the rate of technological development during the last 60 to 70 years, the innovations were grouped into three periods, based on the point in time when commercial development work was started. Periods selected were:

Early 20th century (1890–1919);
Post-World War I (1920–44);
Post-World War II (1945–64).

Each period encompasses a time of substantial growth in this country's economy. Furthermore, the post-World War I and II periods are somewhat similar in that during both, wartime technology was rapidly reoriented to consumer and industrial applications, resulting in a number of significant innovations. Considering the difficulty of matching individual economic characteristics, the three time periods provide a reasonably accurate basis for comparison.

The results of this analysis are shown in exhibit 3. As this chart indicates, the overall lapsed time for technological development has declined during the last 60 to 70 years, from a mean of 37 years in the early 20th century period, to 24 years during the post-World War I period, to 14 years during the post-World War II period. Surprisingly, the primary reduction in the overall period is the result of a decrease in the incubation period rather than in the commercial development period. The incubation period declined from 30 to 9 years during the last 60 to 70 years, whereas the commercial development period only declined from 7 to 5 years. The results suggest that the acceleration in the rate of technological development can primarily be attributed to the increasing sophistication and activities of business and industry in identifying potential commercial applications of technology. The decrease in the incubation period can be expected to continue in the future as business and industry devote more of their efforts to product and corporate planning directed at the problem.

The relatively small change in the commercial development period suggests that perhaps engineers and scientists have always been reasonably adept at converting a technological discovery to a commercial product or process once the direction and objective of these efforts were determined. However, as exhibit 2 indicates, several innovations were converted into commercial products in 3 years or less, and three of these innovations, semiconductors, nuclear power generation, and integrated circuits, were among the most recent. It is therefore reasonable to expect that the rate of commercial development can be increased to some extent if sufficient funds are allocated. With the continuing increase of expenditures by the Federal Government and private industry for research and development, the lapsed time for commercial development can be expected to decrease further in the future. However, considering that a certain amount of inertia exists in the area of commercial development, it is unlikely that any dramatic reductions will be made during the next 5 to 10 years.

Other factors that could be expected to influence the rate of technological development are also summarized in exhibit 3. This analysis suggests some interesting patterns concerning the effects of these factors on the incubation period. For example, innovations with industrial applications have an incubation period approximately twice that of those with consumer applications; and innovations developed with private industry funds also have an incubation period approximately twice that of those funded by the Federal Government. However, no significant difference was found in the incubation period between innovations developed in existing (secondary) industries and new (primary) industries.

Despite their rather substantial effect on the incubation period, none of these factors were shown by this study to have had a significant influence on the commercial development period. Logic would tend to suggest that the rate of commercial development for innovations sponsored by the Federal Government would be much faster than for those financed by private industry, and that industrial innovations would have a faster rate of commercial development than consumer innovations. But no such pattern was evident from the analysis. Similarly, very little difference existed between the commercial development periods for primary and secondary type innovations.

The Rate of Diffusion of Technology. As indicated above, the rate of technological diffusion was determined by measuring the lapsed time required to attain levels between two established sets of economic benchmarks: one based on percent of gross national product which provides a measure of the relative impact on our total economy; and

EXHIBIT 3. SUMMARY OF THE INFLUENCE OF VARIOUS FACTORS ON THE RATE OF TECHNOLOGICAL DEVELOPMENT

Factors influencing the rate of technological development	Mean lapsed time (Years)		
	Incubation period	Commercial development	Total development
Different time periods:			
Early 20th century (1890-1919)	30	7	37
Post-World War I (1920-44)	16	8	24
Post-World War II (1945-64)	9	5	14
Type of market application:			
Consumer	13	7	20
Industrial	28	6	34
Source of development funds:			
Private industry	24	7	31
Federal Government	12	7	19
Type of innovation:			
Primary	19	6	25
Secondary	18	8	26

the other, an absolute measure, based on fixed levels of output. The lapsed time required by each of the 20 innovations under investigation to reach the various relative and absolute economic levels is shown in exhibits 4 and 5.

The analysis of the changes in the rate of diffusion of technology during the last 60 to 70 years is similar to that made on changes in the rate of technological development, except that innovations were allocated to the three time periods based on the date of commercial introduction rather than the start of commercial development. The time periods remained the same—1890–1919, 1920–44, and 1945–64.

Exhibit 6, which shows the results of this analysis, provides an interesting insight into changes that have occurred in the rate of diffusion of technology during the last 60 to 70 years. It is evident that the rate of diffusion has definitely accelerated during this period, but that the acceleration has taken two different forms. The first is revealed by comparing the lapsed time to reach each economic level for innovations introduced during the first part of the 20th century and during the post-World War I period. At each economic benchmark, the rate of diffusion for the more recent innovations was two to three times that of earlier innovations.

The second is revealed by comparing innovations introduced during the post-World War I and post-World War II periods. Although the rate of diffusion was almost identical during the early stages of economic growth (i.e., 0.02 and 0.05 percent of GNP), the time required for post-World War I technological innovations to reach the higher economic levels was considerably longer than for post-

EXHIBIT 4. RATE OF ECONOMIC GROWTH FOR SELECTED TECHNOLOGICAL INNOVATIONS MEASURED IN RELATION TO GROSS NATIONAL PRODUCT

Technological innovation	Date of commercial introduction	Lapsed time (years) required to reach economic levels								
		0.02 percent GNP	0.05 percent GNP	0.10 percent GNP	0.15 percent GNP	0.20 percent GNP	0.25 percent GNP	0.50 percent GNP	0.75 percent GNP	1.0 percent GNP
Aluminum	1892	14	23	50	62	67	>72	----------	----------	----------
Motor vehicle transportation	1894	5	7	9	10	11	13	15	17	20
Synthetic resins	1910	<25	29	31	36	37	41	>55	----------	----------
Air transportation	1911	8	17	25	26	26+	28	29	30	30+
Electronic vacuum tubes	1920	5	8	23	23	>44	----------	----------	----------	----------
Radio broadcasting	1922	1	2	3	4	6	7	22	>42	----------
Frozen foods	1925	9	12	15	21	26	27	31	38	40
Vitamins	1937	5	>28	----------	----------	----------	----------	----------	----------	----------
Synthetic fibers	1939	2	6	13	15	22	25	>25	----------	----------
Synthetic rubber	1940	2	2+	3	4	>24	----------	----------	----------	----------
Antibiotics	1940	5	5+	10	>24	----------	----------	----------	----------	----------
Television broadcasting	1945	2	2+	3+	4−	4	4+	5	19	>19
Titanium	1950	6	>14	----------	----------	----------	----------	----------	----------	----------
Electronic computers	1950	6	8	11	13	14	>14	----------	----------	----------
Semiconductors	1951	5	7	9	>13	----------	----------	----------	----------	----------
Numerical control	1955	9	>9	----------	----------	----------	----------	----------	----------	----------
Nuclear power generation	1957	>7	----------	----------	----------	----------	----------	----------	----------	----------
Freeze-dried foods	1961	>4	----------	----------	----------	----------	----------	----------	----------	----------
Integrated circuits	1961	>3	----------	----------	----------	----------	----------	----------	----------	----------
Synthetic leather	1964	>1	----------	----------	----------	----------	----------	----------	----------	----------

EXHIBIT 5. RATE OF ECONOMIC GROWTH FOR SELECTED TECHNOLOGICAL INNOVATIONS MEASURED BY ABSOLUTE LEVELS OF OUTPUT

Technological innovation	Date of commercial introduction	Lapsed time (years) required to reach economic levels							
		$50 million	$100 million	$250 million	$500 million	$750 million	$1,000 million	$1,500 million	$2,000 million
Aluminum	1892	23	24	53	63	68	70	>72	----------
Motor vehicle transportation	1895	8	10	12	15	16	17	20	28
Synthetic resins	1910	26	29	31	36	41	43	49	52
Air transportation	1911	10	11	20	21	22	23	23+	24
Radio broadcasting	1922	2	3	4	7	8	21	>42	----------
Electronic vacuum tubes	1920	7	8	22	23	35	>44	----------	----------
Frozen foods	1925	10	12	15	25	26	27	29	31
Vitamins	1937	5	6	>28	----------	----------	----------	----------	----------
Synthetic fibers	1939	2	3	11	14	19	22	24	>25
Synthetic rubber	1940	2−	2+	3	11	22	>24	----------	----------
Antibiotics	1940	4	6	10	>24	----------	----------	----------	----------
Television broadcasting	1945	2	2+	3	3+	4	4+	8	15
Titanium	1950	4	>14	----------	----------	----------	----------	----------	----------
Electronic computers	1950	5	6	8	11	13	14	>14	----------
Semiconductors	1951	3	4	7	9	14	>14	----------	----------
Numerical control	1955	6	10	>10	----------	----------	----------	----------	----------
Nuclear power generation	1957	6	>7	----------	----------	----------	----------	----------	----------
Freeze-dried foods	1961	4	>4	----------	----------	----------	----------	----------	----------
Integrated circuits	1961	3	>3	----------	----------	----------	----------	----------	----------
Synthetic leather	1964	>1	----------	----------	----------	----------	----------	----------	----------

Exhibit 6. Summary of the Influence of Various Factors on the Rate of Technological Diffusion

Factors influencing the rate of diffusion of technology	Mean lapsed time (years)			
	0.02 percent GNP	0.05 percent GNP	0.10 percent GNP	0.20 percent GNP
Different time periods:				
Early 20th century (1890-1919)	9	18	29	35
Post-World War I (1920-44)	4	6	11	18
Post-World War II (1945-64)	5	6	8	9
Type of market application:				
Consumer	4	7	10	16
Industrial	8	15	25	29
Source of development funds:				
Private industry	5	10	15	25
Federal Government	6	8	12	20
Type of innovation:				
Primary	6	13	20	27
Secondary	5	6	9	17

World War II innovations—18 years as against 9 to reach 0.20 percent of GNP. There is further evidence that our post-World War II economy is able to ingest technology at a faster rate: post-World War II innovations required only 4 years to grow from 0.02 percent to 0.20 percent of GNP, whereas post-World War I innovations required 14 years, or, more than three times as long. However, two other considerations must be introduced into any evaluation of these findings:

1. Innovations introduced during the post-World War I period were primarily in consumer applications, which, subsequent analysis revealed, tend to have a faster rate of economic growth than the industrial innovations which characterized the post-World War II period.
2. Since post-World War II innovations that reached the higher economic levels were those with the fastest rate of growth, it is quite possible that an analysis such as this undertaken in another 10 years would show innovations with slower growth rates reaching the higher economic levels. Thus, the average length of time required to attain these levels would be increased.

Although it is impossible to ascertain the exact magnitude of the bias these two factors introduce into these findings, they act in opposite directions and perhaps offset each other to some extent.

Despite these mitigating factors, the conclusion that the rate of diffusion of technology has accelerated substantially during the last 60 to 70 years is quite evident. Furthermore, this rate has increased not only in the early stages of commercial growth, but apparently it accelerates as the extent of diffusion increases. The net result is that the lapsed time required for technology to produce widespread effects on our economy and society has decreased significantly during this century—perhaps by a factor of four or more.

Findings shown in exhibit 6 provide an indication of the role of such factors as the nature of the application, source of development funds, and type of innovation on the rate of diffusion of technology. Of these three, the type of market application appears to be of particular importance, since consumer innovations had a rate of commercial growth approximately twice that of industrial innovations—4 years as against 8 to reach a level of 0.02 percent of GNP, and 16 years as against 29 to reach 0.20 percent of GNP. Apparently, the market for consumer innovations is so much larger than industrial market applications that their potential economic impact and rate of economic growth is greater.

The analysis of the rate of diffusion between innovations financed by public and private development funds provides an indication of the effects of the Federal Government's defense and space programs. Only a small variation was indicated between the two groups of innovations during the early stages of economic growth, but at the higher economic levels, the rate of growth is greater for innovations whose development was financed by the Federal Government. For example, it required 20 years for private industry financed innovations to grow from 0.02 percent to 0.20 percent of GNP, whereas Federal Government financed innovations required only 14 years to attain the same levels.

Freedom from patent restrictions may be a factor accounting for the faster overall rate of diffusion of federally supported developments. Innovations financed by private industry often are accompanied by a certain degree of patent protection for the sponsoring individual or company. This patent protection restricts other companies' access to the innovation and provides the patent owner with certain exclusive rights to exploit its commercial application. Thus, commercial exploitation of such innovations would likely involve a single firm. In contrast, most technological innovations developed with Federal Government funds are free of patent restrictions, and, as a result, commercial exploitation of such an innovation might be undertaken simultaneously by a number of firms. When more companies compete in a new area of technology, total investment is normally higher and the rate of economic growth is also probably greater.

A comparison of innovations introduced into existing industries (secondary innovations) with those that required the creation of an entire new industry (primary innovations) revealed a pattern similar to that found between publicly and privately financed innovations. The time required to attain the lower levels of economic growth was approximately equal—6 years for primary innovations to reach a level of 0.02 percent of GNP as against 5 years for secondary. However, secondary innovations reached a level of 0.10 percent of GNP in 9 years as compared to 20 years for primary innovations to reach the same level. These data appear to indicate that the overall rate of economic growth for secondary innovations is approximately twice that of primary innovations.

Thus, the rate of development and diffusion of technology appears to have accelerated substantially since the early part of this century, and even since the post-World War I period. For example, innovations introduced during the early part of the century required an average lapsed time of 36 years from the start of commercial development for output to equal 0.10 percent of the gross national product (approximately $625 million at 1964 economic levels). Post-World War I innovations required 19 years to attain the same economic level, and post-World War II innovations only 13 years. Furthermore, such factors as the source of development funding, type of application, and industry structure into which the innovation is introduced have been demonstrated to have an important effect on the rate of development and diffusion of technology.

5. Conclusions

The Commission's principal interest in the rate of development and diffusion of technology can be summarized by two questions:

1. Is the rate of development and diffusion of technology accelerating as a result of rapidly increasing research and development expenditures by private industry and the Federal Government?
2. If this rate of development and diffusion is accelerating, are the changes caused by technology occurring at such a rapid pace that natural forces within our economy and society cannot cope with them?

The 20 major innovations examined and analyzed in this study are only a small sample of the hundreds and thousands of technological innovations that have been introduced in our economy in recent years and, therefore, there are acknowledged limitations on the extent to which these conclusions can be generalized to encompass the entire field of technology. Nevertheless, the results of this investigation have provided some answers to these questions. As noted in section 4, the rate of development and diffusion for technological innovations introduced during the post-World War II period (1945–64) was twice the rate for those introduced during the post-World War I period (1920–44), and three times the rate for innovations introduced during the early part of the century (1890–1919). Furthermore, the lapsed time between a basic technical discovery and the recognition by business and industry of the commercial potential of such a discovery has also declined, from 30 years for innovations in the early part of this century to 9 for those introduced during the post-World War II period. Therefore, it is quite evident that the rate of development and diffusion of technology is increasing, and that there is no logical reason to expect this is not to continue to increase during the next 5 to 10 years.

Furthermore, although the rate of development and diffusion is increasing, the lapsed time from basic technical discovery to the point where significant social and economic problems become evident is still relatively long. For technological innovations introduced during the post-World War II period, an average period of 9 years ensued from the basic technical discovery before business, industry, or the Federal Government recognized the commercial potential of the discovery: An additional 5 years were required to convert the basic discovery into a commercial product or process, and 5 more years passed before a level of output equal to 0.02 percent of GNP was reached. Therefore, an average lapsed time of 19 years from basic discovery and 10 years from start of commercial development was required for a technological innovation to reach an economic level where about 6,000 to 8,000 jobs would be directly affected. To reach an economic level where significant social and economic effects would probably become evident (perhaps at a level equal to 0.10 percent of GNP) an average additional 3 years was required.

From these data, it is apparent that the present rate of development and diffusion of technology does not require the institution of an "early warning system" to identify potential major technological innovations in their early stages of research and development. Almost without exception, those technological innovations that will have a significant impact on our economy and society during the next 5 years have already been introduced as commercial products or processes: Those that will have a significant impact during the 1970–75 period are already at least in a readily identifiable stage of commercial development.

The real problem in dealing with the effects of changes on our society and economy caused by the introduction of new technological innovations is not the anticipation of technical discoveries far in advance of their commercial development, but rather, of adequately identifying and assessing the total changes that a given technological innovation will produce. Most of the direct effects on employment and industry structures are somewhat obvious and not difficult to predict; however, the indirect effects of technology are often equally important but not nearly as evident. For example, the direct effect of the introduction of the oxygen steelmaking process into the steel industry will be to reduce employment in a segment of steel mill operations and to lower production costs. One of the indirect effects will be to change the source of energy for this portion of the steelmaking process from fuel oil to electrical power, thereby eliminating several million gallons of fuel oil presently consumed each year by the steel industry.

The Federal Government should emulate private industry's efforts to assess the direct and indirect effects of technological innovation. To compete effectively, companies are finding it increasingly important to anticipate changes. Furthermore, they have learned that this forecasting is not a part-time job and that they cannot gain an adequate insight into these changes simply by obtaining a consensus of opinion. All too often, individuals within a field are unaware of outside developments that will have an important impact on their operations, and outsiders, having no perspective to gage the practical difficulties involved in applying a new technology, often make totally unrealistic estimates of the rate of technological change. Thus, as business and industry have already discovered, the accurate interpretation and forecasting of technological change require an organization with unique capabilities which devotes full time to these activities. The Federal Government also needs this type of staff organization to monitor and analyze the impact of technology. Furthermore, rather than limiting these efforts to forecasting the impact on the labor force, such a Federal organization could provide valuable information applicable to transportation policy, utility regulation, education and training requirements, antitrust legislation, and a host of other Federal, State and local government activities.

This investigation has also supplied a valuable tool for monitoring technological innovations. It provided an insight into the influence of such factors as the source of development funds, nature of the application, and type of innovation on the rate of development and diffusion of technology, and indicated that:

> **technological innovations with consumer applications are developed and diffused at a rate considerably faster than that for innovations with industrial applications;**
>
> **innovations introduced into an existing industry are developed and diffused at a rate faster than that for innovations requiring the creation of an entire new industry;**
>
> **innovations developed with Federal Government funds have a slightly faster rate of development and diffusion than those developed with private financing.**

These findings provide a crude but useful priority system that can be used to assess the rate at which the effects of a new technological innovation will be felt on our economy. For example, the rate of diffusion for a major technological innovation with consumer applications introduced into an existing industry could be very rapid, as the rapid growth of television and commercial jet airline transportation has demonstrated. On the other hand, major technological innovations with industrial applications requiring the creation of a new industry (such as the laser) could be expected to have a relatively slow rate of diffusion. In a similar manner, the influence of the source of development funding can be incorporated into any assessment of the rate of diffusion of a technological innovation.

By using these subjective interpretations in combination with some of the more objective data presented in this study, a system for assessing the rate of development and diffusion of technology could be instituted and applied to technological innovations as they are introduced into our economy. This system could determine how closely each should be monitored and how quickly associated changes are likely to occur. Perhaps the end result of these efforts might be a complex "forecasting model" of current and anticipated technological innovations which would not only indicate the direct and indirect effects on our economy and society, but also project the rate at which changes will occur. Such a model would certainly be of considerable help to public and private organizations in understanding many of the changes occurring in our economy and in coping with the problems resulting from these changes.

APPENDIX

A History of Recent Technological Innovations

by Frank Lynn, Thomas Roseberry, and Victor Babich

Just as the study of the history of nations, societies, and cultures provide a perspective against which present social and political changes can be interpreted, so the study of the history of technology provides a basis for assessing the impact of present and future technological innovations on our economy and society. This investigation of changes in the rate of development and diffusion of technology entailed a study and analysis of the history of 21 technological innovations that have had a significant social and economic impact during the last 60 to 70 years. (One of these innovations, magnesium, was not included in this analysis.) As the investigation progressed, it became painfully evident that the type of detailed historical and economic data required to gain an insight into the process of technological innovation is difficult and time consuming to obtain, particularly for many of the innovations introduced during the last 20 years. To assist others with similar interests in the subject, a brief history of the chronology and economic growth of the 21 technological innovations that formed the basis of the analysis is presented in this appendix.

1. Major Technological Innovations in the Field of Electronics

Perhaps this study of major technological innovations in the field of electronic circuitry can best be summarized by the comments several years ago of the vice president of research and development for a major electronics firm. He said that through past experiences he had developed a "formula" for estimating how long it would take for innovations in the electronics field to pass from laboratory development to widespread commercial application. His formula consisted of estimating how fast progress could be made under the most favorable conditions, and dividing this by a factor of two, since the rate of technological progress in the electronics field was generally twice as fast as anyone considered possible. Based on the most recent progress in the field of integrated circuits, perhaps he will soon be changing the divisor to a factor of three.

As the foregoing suggests, the rate of development and diffusion for major technological innovations in the electronics field is quite rapid. This and other considerations make innovations in the field of electronic circuitry of particular interest to this investigation. Two innovations considered here, vacuum tubes and semiconductors, played a critical role in the development of a number of other innovations which have had a profound influence on our way of life. The vacuum tube made possible the commercial development of the entire radio and television broadcasting industry. The semiconductor was vital in bringing the electronic computer from a scientific and research tool to where it is today, an accepted part of most business operations. The third innovation, integrated circuit devices, has not as yet reached a stage of development where its impact can readily be assessed, but it could provide us with such new products as wristwatch radios, television sets that hang on the wall like a painting, and tiny computers to control automobiles on the highways. Furthermore, integrated circuits have the potential to alter the entire structure of the electronic industry and affect the type and number of people now employed in it.

Although all of these innovations are concerned with the detection and amplification of electronic impulses, semiconductors and integrated circuit devices are not simply further refinements of the basic vacuum tube. Each of these innovations represents not only a new field of science and technology, but also involves new concepts in circuit design and technology. A transistor ordinarily cannot be simply substituted for a vacuum tube nor an integrated circuit device substituted for several vacuum tubes or transistors. Each innovation is so different in theory and operation that a circuit designer or engineer working in one of these fields ordinarily cannot function in either of the other without retraining. Thus, each of these innovations—vacuum tubes, semiconductors, and integrated circuit devices—is a major scientific and technological achievement in its own right. Each has made possible the development of other major new electronic innovations, and each has created a major new industry with companies founded on a new technology.

The Vacuum Tube

The vacuum tube is any sealed device that operates by controlling the flow of free electrons in a vacuum or gas, and must be ranked as one of the most significant technological innovations of the last 60 to 70 years. Not only was it a key element in the commercial development of wireless communications and radio and television broadcasting, but it also became one of the basic cornerstones of the entire electronics industry. Considering the importance of these industries in our economy and way of life, the vacuum tube has indeed been an important technological innovation.

Most of the basic research in the vacuum tube field was done by individuals such as Edison, Fleming, and Richardson, who were concerned with the basic phenomena of the flow of the electrons from a heated wire in an evacuated container (see exhibit 1). The primary discovery in this field was made by De Forest in 1906, when he invented the first crude vacuum tube by adding a third element, a control grid, to the two-element tube previously developed by Fleming. The full importance of this discovery was not evident immediately, but emerged slowly during the next 6 years as De Forest and Armstrong experimented with the three-element vacuum tube and demonstrated the feasibility of using it to detect, amplify, and generate radio waves.

The primary impetus to commercial application was provided by Langmuir and Arnold in 1913, when they developed a high-vacuum tube with the reliability and long operating life essential for use in commercial wireless transmission and reception. This discovery marked the transition of vacuum

EXHIBIT 1. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF THE VACUUM TUBE

Basic Research and Investigation:

1880: Elster and Geibel experimented with glass bulbs containing an electrically heated wire and metal plate.

1883: Edison discovered that a current flows from the hot filament of a light bulb to a plate inside the bulb ("Edison Effect").

1901: Richardson published a paper outlining the fundamental theory of thermionic emission.

1904: Fleming patented a two-element vacuum tube (diode) for use as a "wireless valve."

Incubation Period:

1906: DeForest developed the first crude vacuum tube (triode) by adding a grid to Fleming's two-element tube.

1912: De Forest and Armstrong demonstrated the feasibility of using a triode to detect, amplify, and generate radio waves.

1913: Langmuir and Arnold developed the high-vacuum tube that made possible commercial application of vacuum tubes.

Commercial Development:

1914: American Telephone & Telegraph Co. obtained rights to DeForest's triode for radio transmission and reception.

1915: The use of vacuum tubes for long-distance radio transmission and reception was demonstrated.

Commercial Growth:

1920: Commercial production of vacuum tubes began.

1920: A cross-licensing agreement involving the use of basic radio and vacuum tube patents was reached among A.T. & T., General Electric, and RCA.

1921: Westinghouse also entered into this cross-licensing agreement.

1928: Zworykin developed the first electronic television transmission tube.

1929: RCA offered licenses for the manufacture of vacuum tubes to any reputable company.

1941: The development of radar created a new market for high-power vacuum tubes.

1947: The emergence of television as a major consumer product provided an important new market for the cathode-ray type of vacuum tube.

tube development from a largely individual undertaking to one primarily supported by such major companies as General Electric and American Telephone & Telegraph. These firms continued to experiment with vacuum tubes in wireless transmission and in 1915 their feasibility for long-distance radio transmission and reception was successfully demonstrated.

The first commercial production of vacuum tubes began in 1920, when an event occurred which undoubtedly contributed substantially to the commercial development of the vacuum tube industry during the next 10 years. After World War I, the Federal Government became concerned over the attempts by the British Marconi Co. to obtain a dominant patent position in the worldwide use of vacuum tubes in wireless transmission and reception. As a result, the U.S. Navy encouraged the establishment of a new company, Radio Corp. of America, to acquire and consolidate radio and vacuum tube patents for use in the United States. After its establishment, RCA negotiated a cross-licensing agreement with A.T. & T. and General Electric for the use of basic radio and vacuum tube patents in this country. The following year, Westinghouse Corp., also a major company in the field of wireless communications, was included in this licensing agreement.

Although these agreements did not provide complete free competition in the field of wireless communications (since only the four companies had access to these patents), they did establish a more competitive environment in the industry. Several years later, in 1929, the licensing agreement was broadened to make these patents available for licensing to any interested company. This agreement stimulated a free exchange of technical knowledge in the vacuum tube field and removed any limitations to competition that existed because of patent restrictions.

Prior to World War II, the economic growth of the vacuum tube field was closely linked to the commercial development of the radio broadcasting industry. During the 10 years from 1940–50, three major electronic developments—radar, microwave transmission, and television—provided new markets for highly specialized versions of the basic vacuum tube. The significance of these new applications is indicated by the fact that the output of conventional vacuum tubes reached a peak in 1957 at a level of $384 million, and has declined since that time until it stood at a level of only $272 million in 1964. However, output of television tubes and high-power vacuum tubes for these new applications have continued to increase, and their output presently accounts for more than 60 percent of the total output of the vacuum tube industry.

Semiconductors

The second major innovation in the field of electronic circuitry is the semiconductor. To date, semiconductor devices—transistors, diodes, and silicon controlled rectifiers—have had their greatest impact in military and commercial applications, particularly in the field of electronic data processing. Recently, they have begun to have their effect on consumer product areas with the development of transistorized radio and television sets.

The semiconductor provides an interesting example for this investigation because of its impact on the electronic industry. The development of the transistor and other semiconductor devices which followed created a new industry dominated by such companies as Texas Instruments and Fairchild Semiconductors, which evolved out of this new technology, and by companies such as Motorola, which originally were in facets of the electronics industry other than the vacuum tube field. Although many of the major vacuum tube manufacturers produce semiconductor devices, they have not dominated the semiconductor industry despite the obvious advantages they had when this new industry was in its early stages of development and growth.

The development of the transistor and other semiconductors contributed to another significant change in the electronics industry between 1945 and 1955. Because of the growth in size and technological capability of the industry during World War II, companies in this field began to look to research and development as a major source of new products and competitive advantage. With this orientation, the electronic industry has become accustomed to investing heavily in research and development and to risking large sums of money to exploit innovations that emerge from this intensified research and development effort.

The discovery and development of semiconductors has an interesting chronology (see exhibit 2). Early research efforts date back to the 1900's, when semiconductor devices were investigated as a means of amplifying radio signals; however, these efforts were abandoned when the development of the vacuum tube provided an answer to this problem. More recent research during World War II resulted in the development of silicon and germanium diodes and selenium rectifiers for use in radar and other military electronic equipment. These technically are semiconductor devices, but are limited in their application and did not provide the basis for the development of the semiconductor industry. (In many respects, they were similar to the special synthetic rubbers developed in this country during the 1930's.)

EXHIBIT 2. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF SEMICONDUCTOR DEVICES

Basic Research and Investigation:
- **1885: Point-contact rectifiers were discovered and used in commercial applications until they were displaced by the development of the vacuum tube.**
- **1930: The development of selenium and cuprous oxide rectifiers stimulated interest in semiconductor devices.**
- **1931: A good theory of semiconductor phenomena was published.**

Incubation Period:
- **1941: The silicon and germanium diode were developed for use in radar units.**
- **1942: The selenium rectifier was developed.**
- **1946: The silicon photocell was developed.**
- **1947: Bell Laboratories' research work in solid-state physics produced a breakthrough in semiconductor technology.**

Commercial Development:
- **1948: Bardeen and Brattain developed the point-contact transistor at Bell Laboratories.**
- **1950: Shockley published *Electrons and Holes in Semiconductors*, a book that presented the theory of semiconductor devices.**

Commercial Growth:
- **1951: Western Electric and Raytheon began commercial production of point-contact transistors.**
- **1952: Bell Laboratories held a symposium for companies interested in obtaining a license to produce transistor devices.**
- **1954: Texas Instruments announced development of the silicon-grown junction transistor.**
- **1955: The diffusion process for manufacturing transistors was developed.**
- **1956: The Federal Government's antitrust action against Western Electric Co. resulted in an agreement to make all of Western Electric's and Bell Laboratories' patents available to any company on a royalty-free basis.**
- **1956: The Department of Defense signed contracts with about a dozen private companies to purchase semiconductor devices providing these companies would build substantial production facilities for these devices.**
- **1957: The Esaki tunnel diode was developed in Japan.**
- **1958: The parametric amplifier was developed.**

The primary discovery in this field came as a result of research work in solid-state physics conducted at Bell Laboratories after World War II. In 1948, Bell Laboratories announced the development of the point-contact transistor, the fundamental innovation in the semiconductor field. This discovery was followed 2 years later by the publication of a book by Shockley which provided a detailed explanation of the complex theory of semiconductor devices. From this point, the conversion of this basic discovery into a commercial product proceeded very rapidly.

Initial manufacturing of semiconductor devices began at Western Electric in 1951, and was followed soon thereafter by production at Raytheon. The following year, in 1952, an event critical in the development of the semiconductor industry occurred: Bell Laboratories held a meeting at which they divulged to about 50 interested companies the technical knowledge they had developed concerning the fabrication and design of semiconductors. As a result, several companies decided to enter the semiconductor field and obtained licenses from Bell Laboratories to produce these devices. During the next few years, technical developments occurred very rapidly, and included the development of new semiconductor devices and manufacturing techniques.

The next major impetus to the development and growth of the industry occurred in 1956 with two unrelated events that combined to stimulate the growth of this industry further. The first was the antitrust action instituted by the Federal Government against the Western Electric Co. As a result of this suit, an arrangement was reached with Western Electric and Bell Laboratories to make all their basic patents in the semiconductor field available to any interested company on a royalty-free basis. This provided an almost free intercompany exchange of information on semiconductor technology, particularly in manufacturing aspects.

The second event was a decision by the Department of Defense to channel $40 million into the semiconductor field during a 3-year period to enlarge the industry's production capabilities. The Defense Department contracted with 12 companies to produce a limited number of transistors for military and defense applications on the condition that they build production facilities capable of manufacturing 10 to 12 times the number of semiconductor devices. By this action, the Federal Government created a semiconductor production capacity of about 1 million units a year; since production yields were very low, these contracts actually resulted in the creation of a potential semiconductor production capacity of more than 10 million units. Considering that total semiconductor output at the time was approximately 14 million units, the Federal Government greatly accelerated the industry's growth by providing it with an incentive to find commercial applications for the excess capacity created by these Government contracts.

By funding most of the research and development work in this field and guaranteeing a market for these devices through purchase contracts, the Federal Government provided a low-risk investment which certainly contributed to the willingness of companies to enter this new field. Although the total amount of Government research and development funding in the field and its total purchases of devices could not be determined, it is quite evident that the Federal Government played a critical role in accelerating the establishment and growth of the semiconductor industry.

Integrated Circuits

Integrated circuit devices are the most recent major innovation in electronic circuitry. In some respects, integrated circuits are a logical extension of semiconductors in that both these innovations utilize the basic atomic structure of materials to control electronic circuits. However, one fundamental difference exists between semiconductors and integrated circuits that makes the latter a major new development in electronic circuit technology. In conventional electronic circuits employing either vacuum tubes or semiconductors, discrete electronic components are assembled and interconnected to form desired circuits, a number of which are then assembled and interconnected to form an electronic device. However, by using integrated circuits, individual components are eliminated and the circuit becomes the basic building block to construct electronic equipment.

Integrated circuits also are a further extension of the trend toward smaller, more reliable, and lower cost electronic circuitry introduced by semiconductor devices. For example, the reliability of integrated circuits is approximately 100 times greater than that of circuits made with discrete components such as vacuum tubes and semiconductors; the compactness is approximately 1,000 times greater than conventional circuitry; and, although the cost of these devices is still generally quite high, integrated circuits have the potential to produce entire circuits at a cost lower than that of a *single* component in a conventional electronic circuit.

The extent of the technological achievements involved in the development of integrated circuits is indicated by the fact that much of the basic theory behind these devices was unknown; therefore, a considerable portion of the development work was accomplished through trial-and-error experimentation. Furthermore, integrated circuit devices required the development of an extremely complex production technology capable of manufacturing under the high-vacuum conditions found in outer space, determining dimensions to tolerances measured in light waves, and controlling the impurities in materials to levels measured in parts per billion.

While the development of integrated circuits was a major technological advancement in itself, these devices are even more important because of the impact they could have on the electronics industry. This industry now is divided into three categories of companies—those mass-producing standardized electronic components such as vacuum tubes, resistors, and capacitors; those purchasing these components and assembling them into circuit units or packages; and those purchasing these circuits and assembling them to form various types of electronic equipment. With integrated circuits, the circuit becomes the basic building block, with the functions usually performed by the individual components an integral part of the physical and chemical structure of these devices. Because the individual components are no longer needed, integrated circuits could eventually eliminate a portion of the component manufacturing segment of the electronics industry. Futhermore, conventional components and circuits are normally assembled and interconnected manually, but with integrated circuit devices the production process is such that it must be completely automated. Therefore, much of the manual labor now involved in the production of electronic circuits may be eliminated with the increasing use of integrated circuits.

Probably the most outstanding feature of integrated circuits as far as this study is concerned is the rate of technological development of this innovation. At times, major technological advances occurred weekly and monthly rather than yearly. (The chronology of integrated circuit development is shown in exhibit 3.)

Initial development work began early in 1959; by 1961 the first integrated circuits were being produced for commercial applications, and one company, Texas Instruments, had developed a computer employing integrated circuits for the Air Force.

Since the characteristics of integrated circuit devices are particularly well suited for military and aerospace applications, most of the research

EXHIBIT 3. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF INTEGRATED CIRCUITS

Basic Research and Investigation:
- 1916: Dr. Langmuir proposed the first theory of thin-film phenomena.
- 1948: Bell Laboratories announced development of the transistor.

Incubation Period:
- 1956: Varo Corp. instituted a research program to investigate integrated circuits.
- 1957: Dr. Brunetti of General Mills and Dr. Stone of Bell Laboratories presented papers dealing with the basic concepts and theories of integrated circuits.
- 1957: IBM initiated research for the Signal Corps on thin-film circuit concepts.

Commercial Development:
- 1958: The Diamond Ordnance Fuse Laboratories developed simple integrated circuit devices.
- 1958: The Diamond Ordnance Fuse Laboratories developed basic fabrication techniques for thin-film circuits.
- 1958: Varo Corp. received a contract from the Office of Naval Research to accelerate research on integrated circuits.
- 1959: Texas Instruments announced development of an integrated circuit device for use in computers.
- 1959: The Air Research and Development Command awarded a major contract to Westinghouse for development work on integrated circuit devices.
- 1959: Lincoln Laboratories developed the first thin-film computer memory.
- 1960: Westinghouse revealed the results of its Air Force contract on integrated circuit development.
- 1960: The Air Force awarded Texas Instruments a contract to build a computer employing integrated circuits for military use.

Commercial Growth:
- 1961: Fairchild Semiconductors introduced the first integrated circuit devices for commercial applications.
- 1961: Texas Instruments produced the first integrated circuit computer for the Air Force.
- 1962: The Bureau of Naval Weapons initiated a program to accelerate the use of integrated circuits in its equipment.
- 1963: Westinghouse announced completion of a $5 million facility for the production of integrated circuits.
- 1963: RCA Laboratories announced a major new technique for producing integrated circuit devices.
- 1964: The average price for integrated circuit devices had dropped from $90/unit in June 1963, to $14/unit by December 1964.
- 1964: The use of integrated circuit devices in nonmilitary applications, particularly computers, began to increase rapidly.

and development work in this field was financed by the Federal Government. The efforts of the Air Force and Navy to accelerate the use of integrated circuits in their electronic equipment was the primary impetus behind the rapid rate of progress in this field. It has been estimated that the Federal Government spent more than $100 million on integrated circuit research and development. In addition, virtually all of the initial integrated circuit production was for military and aerospace purposes. As recently as January 1964, shipments to the Air Force, Navy, NASA, and the National Security Agency accounted for 92 percent of total integrated circuit shipments.

Although there is considerable commercial interest in integrated circuit devices, particularly in the electronic data processing field, commercial applications for this innovation have not reached a point where their impact can be predicted. However, this interest is intensifying as price reductions have accompanied increased output. For example, the average price for integrated circuit devices dropped from $90 per unit in June 1963 to $14 per unit by December 1964, and the unit price is estimated to decline to $9 by the end of 1965. Judging by the electronic industry's interest and investment in this field to date, it is safe to predict that integrated circuits will have a significant impact on the industrial and consumer economy of this country.

Conclusions

A comparison of the economic development of these three innovations (shown in exhibit 4) provides an interesting insight into some of the internal and external factors that influence this rate of diffusion. As this chart indicates, the economic development of the vacuum tube industry follows what might be considered a normal growth curve, with output increasing slowly during the first few years, then accelerating rapidly as new markets and applications increase rapidly, finally stabilizing and then declining as the industry reaches maturity and new innovations make inroads into these markets and applications.

In contrast, the economic development of the semiconductor industry has occurred at a much more rapid rate, being almost a linear rate of growth during the first 10 years of its existence. It required 32 years for the vacuum tube industry to attain a level of output of $500 million, whereas the semiconductor industry reached this level in less than 8 years. The primary reason for this difference in the rate of commercial development is that the initial period of gradually increasing growth in the semiconductor industry was so brief that it was almost nonexistent. A further comparison of differences in the rates of commercial growth is shown in exhibit 5, which shows the lapsed time for each of these innovations to reach the various economic levels used as reference points in this study.

A comparison of the relative rate of commercial growth shown in this chart indicates that during the early stages (up to 0.05 percent of GNP), the rates of growth for vacuum tubes and semiconductors were almost identical. However, beyond that point, the rate of commercial growth for semiconductors was considerably faster, reaching 0.10 percent of GNP in 9 years versus 23 for vacuum tubes. No doubt the depression of the 1930's had a substantial retarding effect on the growth of the vacuum tube industry, but four

Exhibit 4. The Commercial Growth of Major Technological Innovations in the Electronics Field

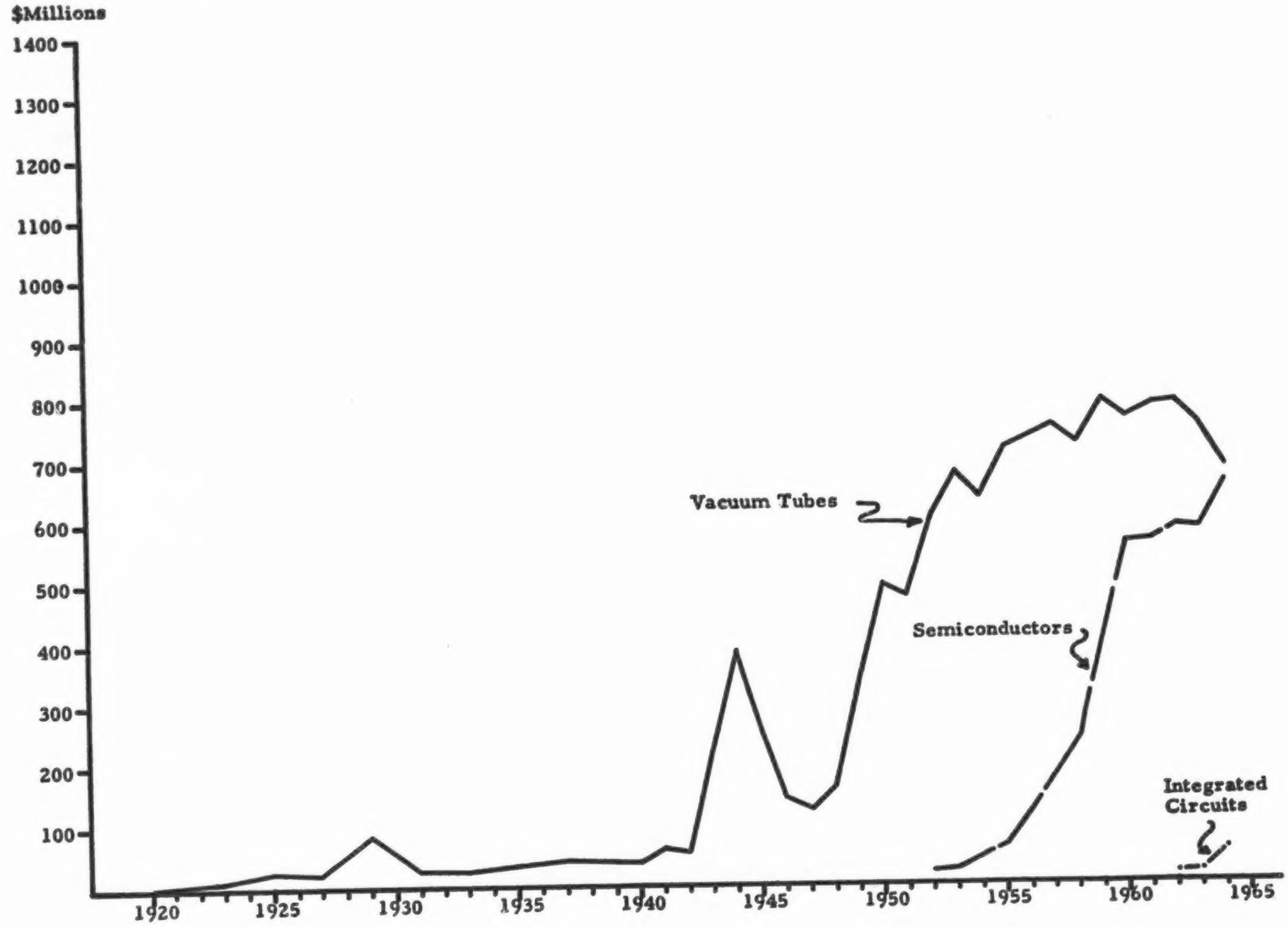


Exhibit 5. A Comparison of the Rate of Commercial Growth for Technological Innovations in the Field of Electronic Circuitry

Criteria for evaluation	Lapsed time (years)		
	Vacuum tubes	Semi-conductors	Integrated circuits
Date of commercial introduction	1920	1951	1961
Relative economic measure in percent of GNP:			
0.02	5	5	>3
0.05	8	7	----------
0.10	23	9	----------
0.15	24	>13	----------
0.20	>44	----------	----------
Absolute economic measure in $ million:[1]			
50	7	3	3
100	8	4	>3
250	22	7	----------
500	23	9	----------
750	35	14	----------
1,000	>44	>14	----------

[1] Measured in constant dollars, 1957–59 index of wholesale prices.

other factors also contributed to the more rapid rate of growth of the semiconductor industry:

1. The Federal Government created an artificial market of substantial proportions for semiconductor devices to encourage a rapid increase in production capacity; in comparison, vacuum tubes had to await the commercial development of wireless transmission and radio broadcasting to create a market for this innovation.
2. By 1951, the electronics industry had reached a point in its economic growth where companies were firmly established and had the financial resources to invest heavily in this new technology; whereas in 1920, the electronics industry was in its infancy and the companies in the field were small, with limited financial resources to invest.
3. Much of the basic research and development work on semiconductor devices was funded by the Federal Government, while most of the research and development work on vacuum tubes was undertaken by individuals and private companies.
4. Almost unrestricted access to basic patents and technical knowledge characterized the semiconductor field, whereas patent restrictions placed some limitations on the availability of technical knowledge in the early years of the vacuum tube industry.

Although it is impossible to assign specific relative values to the contribution which each of these factors made to accelerating the economic growth of the semiconductor industry, it appears that the first two—the creation of an artificial market for these devices by the Federal Government and the ability and willingness of the electronics industry to invest in new innovations—were the most significant in accelerating this rate of diffusion.

A comparison of the rate of commercial growth of integrated circuits with the other two innovations would have provided an interesting opportunity to verify that the rate of diffusion of technology in the electronics industry is increasing. Unfortunately, integrated circuits have not reached a point in their commercial growth where valid comparisons can be made. However, the absolute economic measure of commercial growth indicates that, at least in the very early stages, the rate of diffusion for semiconductors and integrated circuits was about equal. It would be interesting to update this data in 5 years or so to determine if there has been any increase in the rate of diffusion during the last 10 to 15 years.

2. Major Technological Innovations in the Field of Synthetic Materials

This portion of the study is concerned with an investigation of major technological innovations in the field of synthetic materials. The innovations include synthetic fibers, synthetic rubber, synthetic leather, and synthetic resins (plastics other than fibers). In combination, these four innovations supply a unique insight into several different aspects of the process of technological discovery, development, and diffusion:

1. Since each of these developments evolved from the chemical industry and had a number of similar technical and economic characteristics (e.g., high levels of capital investment in plant and facilities and complex production technologies), but occurred in different time periods, they provide an opportunity to determine if the rate of technological development and diffusion is accelerating in the chemical industry.
2. Since the development and marketing of synthetic rubber was completely financed and controlled by the Federal Government, whereas the other developments were privately financed and controlled, they provide an opportunity to evaluate the effect of expenditures of public funds on the rate of technological development and diffusion.
3. They provide an opportunity to compare the degree to which direct versus generalized research objectives bear on the rate of technological development and diffusion since synthetic resins illustrate the generalized development approach and the other three were quite specific in orientation.

Each of these innovations represents a successful effort by the chemical industry to develop and manufacture a synthetic product to capture a significant segment of a large natural materials market. A primary incentive to the development of each of these synthetic raw materials was provided by the wide fluctuations in the quality and price of the natural materials. However, there is one primary difference in this regard. The natural counterparts of synthetic fibers, rubber, and leather are directly identifiable, whereas synthetic resins affected a broad spectrum of materials—wood, paper, glass, rubber, fabrics, and metals. Despite their similarities, the development of each of these synthetic materials was influenced by different sets of considerations which are discussed individually here.

Synthetic Resins (Plastics)

Synthetic resins (plastics) occupy a unique niche in the industrial economy of our country in that they are actually "families" of chemicals (e.g., polyvinyl chlorides, styrenes, epoxies, polyethylenes, polypropylenes, etc.) which in turn are composed of various formulations and compounds that have different physical characteristics and applications. Furthermore, these synthetic resins can be combined with other materials such as fiber glass and asbestos to form materials with unique physical properties.

Because of these properties, plastics have successfully invaded the markets for glass in bottles and window panes; for wood in toys and TV cabinets; for metal in machine parts, small boats, and automobile bodies; for paper in packaging; and in many other consumer and industrial product areas. The unique properties of many of these synthetic resins have also created applications such as high strength adhesives (epoxies) capable of bonding almost anything to anything, water repellent coating (silicones), and lightweight thermal insulation (foamed polystyrene), none of which had existed previously. Because of the widely diversified applications of synthetic resins, this field has grown rapidly during the last 20 years until it now has become a major industry with an output of $2.4 billion in 1964. There are three major resin families that account for more than 60 percent of industry output:

1. *Polyvinyl chloride and copolymers.* Polyvinyl plastics rank third in the synthetic resin industry, representing 11.5 percent of total production value. Flexible polyvinyl chloride accounts for the bulk of the usage, and includes soles for shoes, raincoats, and dolls. Although the resin has historically been lower priced than polyethylene, PVC has been more difficult to mold, resulting in higher production costs. It has found extensive application in product areas that utilize its properties of abrasion resistance, resistance to chemical attack, and physical strength in rigid forms. Rigid forms of PVC, introduced about 10 years ago, are now widely accepted for pressure piping applications, handling of corrosive liquids, and building products. Its unique self-extinguishing property may provide a large market in house siding applications.

2. *Styrenes.* The styrene family of plastics accounts for 15 percent of total industry production. Styrenes are not only used by themselves but in such a variety of compounds and formulations that it is impossible to generalize about their properties and uses. For example, styrene is a component of Buna-S rubber; impact polystyrenes are commonly used in refrigerator door linings and luggage; heat resistant polystyrenes in small radio cabinets; ABS (acrylonitrile-butadiene-styrene) in automotive instrument panels and telephone sets; and foamed polystyrene in picnic jugs, cushioned packaging, and as insulating material in prefabricated wall panels for construction applications. The growing uses of styrene are reflected by the fact that production of this material increased 22 percent from 1963 to 1964.

3. *Polyethylenes.* Polyethylene (a member of the polyolefin family) is the newest of the big three resins, having been introduced commercially in 1941. It accounted for 2.6 billion pounds and $468 million of 1964 synthetic resin production, respectively 26 and 19.5 percent of industry totals. Because polyethylene can be tailored to obtain desired characteristics, its applications are diverse, ranging from consumer goods such as blow-molded bottles to industrial goods like wire and cable coatings.

The technical history of synthetic resins dates back to the 1830's (see exhibit 6) with a number of important chemical discoveries in this field being made during that decade. Most of the research and development work in plastics during the subsequent 60 years was concentrated in developing methods for manufacturing synthetic versions of natural materials (rayon and celluloid) using cellulose as the basic raw material. (Since cellulose is not a basic chemical but rather a chemical compound that is the essential constituent of wood, these are not true synthetic materials.)

The first synthetic plastic, a phenol-formaldehyde resin, was discovered by Baekeland in 1907, and became commercially available 3 years later, with 1910 marking the beginning of the plastics industry. During the next 15 to 20 years, further technical developments in the field were sporadic, largely the result of much trial and error in chemical research.

Both technical and commercial development increased substantially during the 1920's because of three events:

1. Baekeland's basic patents expired and permitted other companies to enter the field of phenol-formaldehyde resins.

2. Several new plastics were developed and introduced, including the alkyd resins, the urea-formaldehydes, and the polyvinyl chlorides.

3. Basic research was begun on the structure of complex chemical compounds.

EXHIBIT 6. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF SYNTHETIC RESINS

Basic Research and Investigation:

1831: The styrene monomer was first isolated.
1833: Braconnot (and Schoenbein in 1845) made discoveries relating to preparation of cellulose nitrate.
1834: Liebig described melamine.
1838: Regnault prepared vinyl resins.
1839: Simon polymerized styrene.

Incubation Period:

1855: Parkes and Spill prepared various articles from a solution of cellulose nitrate and camphor.
1865: Schutzenberger undertook basic research on the preparation of cellulose acetate.
1868: J. W. Hyatt produced celluloid, the first commercial plastic.
1868: Merrick obtained patents on shellac molding compositions.
1869: The Hyatt brothers obtained a patent for making solid collodion.
1869: Berthelot prepared synthetic styrene.
1870: The Albany Dental Plate Co. was organized to produce and sell celluloid.
1871: The Celluloid Manufacturing Co. succeeded the Albany Dental Plate Co. as many unexpected uses for celluloid developed.
1872: Baeyer reported the formation of resinous products from the reaction between phenol and aldehydes.
1890: Kraemer and Spilker did basic work on coumarone-indene resins.
1901: Rohm did basic work on acrylic resin plastics.

Commercial Development:

1907: Baekeland discovered how to control the phenol-aldehyde reaction and began to produce a phenol-formaldehyde resin, the first thermosetting plastic, on a laboratory scale.
1909: Baekeland obtained a patent on his discovery.

Commercial Growth:

1910: The General Baekelite Co. was formed to produce and market phenol-formaldehyde resins.
1911: Matthews obtained a patent on preparation of polystyrene.
1920: Hanns John obtained a patent on urea-formaldehyde resins.
1926: With expiration of Baekeland's basic patents, many firms began to produce phenol-aldehyde resin.
1928: Carothers began fundamental studies of the structure of substances of high molecular weight.
1928: The first commercial vinyl plastics were marketed.
1934: The injection of molding of plastics was introduced.
1936: Acrylic resin sheets (e.g., Plexiglas) were introduced commercially.
1937: Polystyrene was introduced commercially.
1941: Polyethylene was introduced commercially.
1943: Nylon was introduced for molding composition use after being introduced as a fiber in 1938.
1945: Tetrafluorethylene polymers (e.g., Teflon) were introduced commercially.

The development of new plastics during the 1920's stimulated work in fabrication technology for these materials, with the first injection molding machines being imported from Germany in 1934. During the next 5 years, further developments in fabrication techniques produced transfer molding, flexible membrane molding, jet molding, and dry extrusion molding. Additional improvements were also made on earlier fabrication techniques which produced more automatic machine operation and larger molding capacities. This fabrication technology has been an important factor in the growth of the synthetic resins industry because it has provided low-cost manufacturing techniques that have enabled plastics to invade many markets where costs are a critical factor.

As indicated previously, the field of synthetic resins includes a large number of different resins. Only six of these have ever achieved the $100 million level of annual output, and they currently account for two-thirds of the industry production. It is interesting to note that those resins introduced earliest took the longest time to reach this level of output, and those introduced most recently have reached these levels faster. This phenomenon is illustrated in exhibit 7, which indicates that each of the three largest synthetic resins has grown more rapidly than its predecessor.

EXHIBIT 7. COMMERCIAL DEVELOPMENT OF THE THREE MOST IMPORTANT PLASTIC RESINS

Production value, 1964 (millions)	Resin family	Year introduced commercially	Lapsed time (years) to reach level of output		
			$50 million	$100 million	$250 million
$277	Polyvinyl chloride and copolymers.	1928	17	21	35
362	Styrenes	1937	11	13	22
471	Polyethylenes	1941	11	13	17

This suggests that much of the initial industry development is past and the industry's research and development efforts are now focused on specific objectives rather than hit-or-miss development. New formulations are increasingly the result of directed efforts to produce resins with predetermined characteristics. Moreover, the commercial potential of these new formulations can now be better assessed and more vigorously promoted than in the past. Current development efforts, reflecting this attitude, are directed toward development of materials (such as polycarbonates) that have excellent wear resistance, dimensional stability, and heat resistance.

As an industry, synthetic resins manufacturers range widely from large chemical and petroleum companies to small firms. Competition is intense with only a limited amount of protection offered by patents and trade secrets. The variety and ease with which new formulations may be developed from the basic raw materials probably accounts for the large number of small companies in the field. Another important factor is the relatively small capital investment required to enter the formulating portion of this industry.

Synthetic Fibers

Although synthetic natural fibers in the form of rayon and acetate fibers had been in production since 1891, these materials are not considered synthetic fibers since they were made from the same raw material as natural fibers. Nylon, the first synthetic textile fiber, was a true synthetic material since it was completely synthesized from basic chemicals.

The basic research, commercial development, and market development of synthetic fibers was performed by a single organization, the Du Pont Co. The chronology of the discovery and development of this innovation is outlined in exhibit 8. Basic research and investigation in the field began in 1928 when the Du Pont Co. established a research program to investigate the fundamental nature of polymers and other complex chemicals. One result was the accidental discovery of a series of polymers that could be formed into fiberlike strands. Basic research was continued and, in 1935, a polymer called "66" (later named Nylon) was synthesized in Du Pont's laboratory. Polymer 66 exhibited sufficient promise as a synthetic fiber so that Du Pont accelerated development work to produce a commercial synthetic fiber. This effort was successful in the laboratory in 1937, and Nylon was formally introduced to the public the following year. It is estimated that during this period Du Pont invested $2 million on the research and development that produced the first synthetic fiber.

During the first 12 years of the economic growth and development of synthetic fibers (1939–51), Du Pont was the only manufacturer of synthetic fibers because it had exclusive control of product and process patents. During this same period, Du Pont also introduced two other new synthetic fibers, Orlon and Dacron, which further increased the company's dominance of the synthetic fiber industry. This control was partially relinquished in 1951 when Chemstrand was granted a license to manufacture Nylon yarn under Du Pont's patents, and was completely eliminated when an antitrust suit by the Federal Government resulted in Du Pont agreeing to license Nylon patents to all interested companies at reasonable royalties. Since that time, several companies have entered the synthetic fiber field in competition with Du Pont.

Synthetic Rubber

Synthetic rubber is more than another example of a successful effort on the part of the chemical industry to displace natural materials with synthetic materials. In addition, a number of aspects of its discovery and development are unique and of considerable interest to this investigation. For example

—Synthetic rubber was technologically feasible many years before economic and market considerations warranted the exploitation of this innovation in the United States.

EXHIBIT 8. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF SYNTHETIC FIBERS

Basic Research and Investigation:
1884: Chardonnet produced the first commercial rayon fiber from nitrocellulose.
1891: The commercial production of rayon began in France.
1911: Commercial production of rayon began in the United States.
1928: Du Pont initiated a basic research program into the fundamental nature of polymers and other chemical compounds.

Incubation Period:
1930: Du Pont research laboratories discovered a polymer that could be formed into a fiberlike material with some textile properties.
1931: Dr. Carothers and Dr. Hill presented a paper describing the results of Du Pont's research in this field.
1934: Continued research by Du Pont was successful in producing a number of synthetic polymers with sufficient promise to warrant increased effort in the field of synthetic fibers.
1935: Polymer 66 (later called Nylon) was synthesized in the laboratory.

Commercial Development:
1936: A substantial development program was undertaken to produce a commercial synthetic fiber material from Polymer 66.
1937: Nylon was produced in the laboratory in sufficient quantity to permit experimental manufacture of women's hosiery.
1937: Process development was completed.
1938: Nylon was officially announced to the public.
1938: A pilot plant for the production of Nylon was completed and put into operation.

Commercial Growth:
1939: A full-scale plant for producing Nylon was constructed and production began.
1940: Nylon hosiery was first introduced to the consumer market.
1941: A second plant for producing Nylon was placed in operation.
1948: A new synthetic acrylic fiber, Orlon, was developed by Du Pont.
1949: A new synthetic polyester fiber, Dacron, was developed by Du Pont.
1950: Orlon was first marketed commercially.
1951: Chemstrand was licensed to manufacture Nylon yarn under the Du Pont patents.
1952: An antitrust suit by the Federal Government resulted in an agreement by Du Pont to license the patents to all interested companies at reasonable royalties.
1953: Dacron was introduced commercially.
1953: American Enka was licensed by Du Pont to manufacture Nylon yarn.

—The primary impetus for the establishment and growth of the synthetic rubber industry in this country was not based on normal economic and market forces but rather on an artificial shortage of natural rubber created by World War II.

—The entire synthetic rubber industry in this country was created, built, and owned by the Federal Government (from 1940 to 1955) and, for the first 5 years of its existence, most of the output of this industry was purchased by the Federal Government for military use.

Synthetic rubber has a long history of scientific investigation, with most of the basic chemical research being done during the last half of the 19th century and the first decade of this century (see exhibit 9). The first commercial process for producing synthetic rubber was developed and patented in 1910. However, there was very little economic incentive to foster the development of synthetic rubber because no great market for rubber existed at that time.

The initial impetus to the development of synthetic rubber was provided in Germany during

EXHIBIT 9. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF SYNTHETIC RUBBER

Basic Research and Investigation:
1826: Faraday made the first chemical analysis of natural rubber.
1860: Isoprene was isolated as the basic chemical component of natural rubber by G. Williams.
1887: Wallach first produced a crude form of synthetic rubber in the laboratory.
1908: A British firm, Strang and Graham, Ltd., undertook a research program to develop a commercial process for producing synthetic rubber.

Incubation Period:
1910: A process for producing synthetic rubber was patented in England and Germany.
1911: Two American firms initiated research programs aimed at the development of a commercial synthetic rubber.
1915: The British blockade forced Germany to develop and manufacture a synthetic rubber that was unsatisfactory as a replacement for natural rubber.
1922: J. C. Patrick developed a specialized form of synthetic rubber called Thiokol.
1926: The German Government instituted a program of synthetic rubber development to make it independent of natural rubber supplies.
1928: The basic emulsion process for producing synthetic rubber from butadiene was perfected.
1931: Du Pont announced development of a new special-purpose synthetic rubber called Neoprene.
1933: The first truly commercial synthetic rubbers (Buna S and Buna N) were developed and patented in Germany.

Commercial Development:
1934: Pilot plant production of synthetic rubber began in Germany.
1939: Standard Oil Development Co. obtained rights to the German patents, initiated pilot plant production of synthetic rubber in the United States, and announced construction of a full-scale production plant.

Commercial Growth:
1940: Standard Oil Co. of New Jersey announced development of a butyl synthetic rubber.
1940: The Federal Government created the Reserve Rubber Company to manufacture synthetic rubber and coordinate its use for military and commercial purposes.
1941: The Federal Government authorized construction of four synthetic rubber plants.
1942: The Federal Government authorized expansion of synthetic rubber capacity to 400,000 tons and then to 800,000 tons.
1946: The Interagency Committee on Rubber issued a report outlining a national policy concerning the Government's ownership of synthetic rubber production facilities.
1948: The Rubber Act of 1948 extended the Government's ownership of these facilities.
1955: The Government-owned synthetic rubber plants were sold to private industry.
1955: The development of "true" synthetic natural rubbers (polyisoprene and polybutadiene) was announced.
1965: Production of these new synthetic natural rubbers began.

World War I. The British naval blockade cut off the German supply of natural rubber and forced them to develop synthetic rubber materials. Although synthetic rubber was actually produced in Germany during World War I and used for military purposes, this material was not a commercially acceptable substitute for natural rubber. After World War I, interest in the development of a commercial synthetic rubber became dormant because the growing output of natural rubber reduced prices to a level where the production of synthetic rubber was considered to be uneconomical.

A second and more significant impetus to the development of a process for producing synthetic rubber was provided during the 1930's by a combination of two factors:

1. The growth of the automobile industry created a rapidly expanding market for natural rubber that caused rubber prices to increase rapidly.
2. The German Government reached a decision to become self-sufficient in the supply of critical raw materials (including rubber) that came from sources outside of its borders.

These two factors again created interest in Germany and the United States in the development of a commercial synthetic rubber. However, the German efforts were more successful and, in 1933, a German chemical firm developed and patented two synthetic rubbers (Buna N and Buna S) that could be substituted for natural rubber in most applications. Pilot plant production of these synthetic rubbers was begun in Germany in 1934 and in Russia shortly thereafter.

Interest in synthetic rubber in the United States was largely dormant during this period, although two special-purpose synthetic rubbers with limited commercial applications were developed and put into production during the 1930's. The extent of this country's lack of interest in synthetic rubber prior to the start of World War II is indicated by the fact that in 1939, 1,750 tons of special-purpose synthetic rubber were produced in the United States as compared to a world production of more than 100,000 tons. Commercial interest in synthetic rubber in this country did not develop until 1940, when Standard Oil Co. of New Jersey obtained the patent rights to the German processes for producing synthetic rubber and started construction of facilities for manufacturing these synthetic rubbers.

Although Standard Oil Co.'s decision to produce synthetic rubber was made on basic economic and competitive considerations, the real growth of the industry resulted from the outbreak of World War II in Europe and the subsequent involvement of the United States in that war. In 1940, a critical analysis was made of the vulnerability of the U.S. supply of natural rubber and the critical nature of this commodity in the event of a war. As a result of this report, the Federal Government created the Reserve Rubber Co., to manufacture synthetic rubber and coordinate its sale and use for military and commercial applications. Shortly thereafter, the Government authorized construction of four synthetic rubber and raw material plants. The result of these actions by the Federal Government was to increase synthetic rubber production from 22,000 tons in 1942 to 232,000 tons in 1943, and to 764,000 tons by 1944.

With the end of World War II and the elimination of the artificial demand for rubber it created, production of synthetic rubber declined substantially. During this postwar period, the Federal Government continued its ownership of the synthetic rubber and raw material plants until a workable program of disposing of them could be developed. Public ownership of the entire synthetic rubber industry continued until 1955, when the Federal Government finally sold its synthetic rubber and raw material plants to private companies.

As a private industry, the synthetic rubber industry continued to grow rapidly. In the 10-year period from 1955 to 1964, the output of synthetic rubber increased almost 50 percent, from nearly 900,000 tons in 1955 to 1,310,000 tons in 1964. A further stimulus to the continued growth of the industry occurred in 1955 when two new synthetic rubbers—polyisoprene and polybutadiene, true synthetic versions of natural rubber—were developed. The significance of their development lies in the fact that previous synthetic rubbers had to be blended with a certain amount of natural rubber in order to obtain the desired characteristics in tires and other large rubber applications; because of this, the output of synthetic rubber was limited to about 60 percent of the total consumption of rubber in this country.

With the development of true synthetic rubbers, the use of natural rubber in tires and other major applications can be virtually eliminated. As a result, the output of synthetic rubber has increased to where it now accounts for about 75 percent of total rubber consumption. In the future, as more production plants for producing these new synthetic rubbers are put in operation, synthetic rubber is expected to displace natural rubber in most applications and thereby cause further expansion of the synthetic rubber industry.

Synthetic Leather

Synthetic leather is the most recent technological innovation in the field of synthetic materials and, in many respects, it is a greater technological achievement. Because leather, unlike fibers or rubber, is not a homogeneous material but is composed of a number of separate layers with different characteristics, it presented a far more complex problem. In addition, developing synthetic leather was not primarily a problem of chemical synthesis, as in the case of the other synthetic materials, but rather a major chemical engineering accomplishment that required combining a number of layers of existing materials in a unique manufacturing process.

Although synthetic leather is such a recent innovation (introduced commercially in 1964) that the changes it will produce are not evident as yet, it could have an important impact on the leather and shoe industries. Because synthetic leather is a homogeneous product with controlled physical and chemical properties, it will make possible the automation of shoe and other leather product manufacturing. A change in production methods could have important economic effects on the present $700 million market for natural leather, the structure and geographical location of the shoe industry, and the number and type of workers that will be employed in that industry.

For the purposes of this investigation, synthetic leather provides an opportunity to evaluate the changes that have occurred in the rate of development of technological innovations during the last 25 years. Synthetic fibers and synthetic leather were both developed by the Du Pont Co. with no outside research or development assistance from other companies or the Federal Government. Both of these innovations also penetrated large, well-established consumer product markets. However, since their development occurred 25 years apart, they provide an interesting opportunity to compare the rate of development and diffusion for these two time periods. Unfortunately, the economic growth and development of synthetic leather has not progressed to a point where a meaningful comparison can be made of their rates of diffusion, but it is possible to contrast their rates of development.

Very little detailed information is available concerning the chronology of synthetic leather development (see exhibit 10) since it is a recent innovation and occurred completely within the Du Pont organization. It is known that a basic research program in synthetic leather was initiated at Du Pont late in the 1930's and continued for some 20 years, with a temporary suspension of this effort during World War II. In 1950, the development of two new chemical materials, urethane compounds and polyester fibers, made the production of synthetic leather appear technically feasible, and Du Pont's development efforts in this field were accelerated. The basic chemical problems dealing with the synthetic leather were resolved by 1958, but the more difficult manufacturing and engineering problems remained. Laboratory production of synthetic leather was achieved the following year, with pilot-plant production initiated by Du Pont in 1960, followed by construction of a full-scale production plant [illegible] years later.

EXHIBIT 10. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF SYNTHETIC LEATHER

Incubation Period:
1938: Research was begun at Du Pont on the basic structure of leather and methods of producing a synthetic material from chemical products.
1941: Research was discontinued during World War II.
1945: Synthetic leather research was resumed at Du Pont but was largely unsuccessful.

Commercial Development:
1950: The development of urethane compounds and polyester fibers provided new materials that made synthetic leather appear technically feasible.
1955: Du Pont decided to accelerate development work on synthetic leathers.
1958: Chemical problems had been resolved but major production engineering problems remained.
1959: Synthetic leather was produced in the laboratory and preliminary product testing was started.
1960: Pilot-plant production of synthetic leather was started at Du Pont.
1962: Du Pont authorized construction of a full-scale production plant at Old Hickory, Tenn.

Commercial Growth:
1964: Du Pont's synthetic leather, Corfam, was first marketed to the shoe industry.
1965: Du Pont's Old Hickory plant for manufacturing synthetic leather went into production.

The commercial exploitation of Du Pont's synthetic leather (trademarked 'Corfam') provides an interesting contrast to the widespread commercial exploitation of synthetic rubber. Because the basic patents and production knowledge were the exclusive property of Du Pont, the initial marketing of synthetic leather was closely controlled to maximize the company's return on its $25 million investment in the research and development of its innovation. To achieve this objective, Du Pont limited the initial use of synthetic leather to higher priced shoes. Besides allowing a greater margin of profit, this strategy is expected to permit synthetic leather to gain consumer acceptance as a "quality" product that should increase its marketability in less expensive applications when Du Pont's production capability permits the exploitation of these markets. From Du Pont's viewpoint, this tight control on the initial introduction of synthetic leather is very desirable, but such a marketing strategy will undoubtedly inhibit the rate of diffusion of this innovation.

Conclusions

As indicated previously, two innovations, synthetic fibers and synthetic rubber, provide an unusual opportunity to examine the effects of Government funding in accelerating the rate of technological development and diffusion. Synthetic fibers presents one extreme in that the entire development and commercial exploitation of synthetic fibers was controlled by the Du Pont organization. It is estimated that Du Pont invested $15 million in the research and development of their three synthetic fibers and an estimated $400 million in plant and equipment for producing them through 1951, when licensing agreements were signed enabling other companies to enter the synthetic fiber field. The role of the Federal Government in the development and diffusion of this innovation was limited to requisitioning the entire output of the synthetic fiber industry during World War II for wartime uses and filing an antitrust suit against Du Pont which resulted in an agreement in 1952 to make the Nylon fiber patents available to other companies.

On the other hand, the development and commercial exploitation of synthetic rubber presents a complete contrast in that the entire industry in this country was financed and owned by the Federal Government. Even much of the basic research and development work was financed by public funds during World War I and in the 1930's when the German Government developed a commercial synthetic rubber to be independent of natural rubber supplies.

The extent of the Federal Government's participation in the development of the synthetic rubber industry in this country was almost unprecedented. At the start of World War II in Europe, this country did not have a synthetic rubber industry except for two companies that were producing specialized synthetic rubbers. When the vulnerability of this country's rubber supply became evident, the Federal Government undertook a crash program to create a synthetic rubber industry here. During this war period, the Federal Government financed research work on synthetic rubber process and product development, built the synthetic rubber plants and the plants for producing the required raw materials, and contracted with private companies to operate these plants. In addition, the Government purchased virtually all of the output of these plants for military use. It is estimated that the Federal Government's total investment in the synthetic rubber industry amounted to $40 million for research and development and $700 million for production plants and facilities.

There is a remarkable number of similarities between synthetic fibers and synthetic rubber as innovations—they both originated as commercial products at approximately the same time, the investments in research and development were comparable ($15 million for synthetic fibers versus $40 million for synthetic rubber), and the total capital investment in plant and equipment for the period through 1955 is almost equal ($750 million for synthetic fibers and $700 million for synthetic rubber). As a result, they provide an insight into the extent to which the rate of technological development and diffusion can be accelerated if the Federal Government assumes most of the risk involved in investing in an innovation rather than waiting for private industry to do so. As exhibit 11 indicates, the growth of synthetic fibers follows what could be considered to be a normal growth curve—increasing very slowly at first, like that of the synthetic resin industry, and then gradually accelerating. On the other hand, the economic growth of the synthetic rubber industry is almost unbelievable, increasing from $27 million in 1942 to $156 million in 1943, and to $354 million in 1944—a thirteenfold increase in 2 years. A comparison of the time required for each of these innovations to attain the various levels of economic development is shown in exhibit 12.

Comparison of the growth of the synthetic fiber and rubber industries graphically demonstrates the extent to which the Federal Government can accelerate the economic growth of innovations by assuming some or all of the investment risk. For example, with Government financing, the synthetic rubber industry attained a level of output of $250 million in less than 3 years, whereas it required more than 10 years for the synthetic fiber industry to reach this same level of output under private financing. Exhibit 12 also demonstrates the impact which the Federal Government can have on the rate of diffusion of these innovations by creating an artificial market for them. The Federal Government created a guaranteed market for synthetic rubber during World War II by allocating most of its output for military use and limiting the amount of natural rubber that could be used in consumer applications. The magnitude of the market subsidy created by the Government's wartime requirements is indicated by the fact that synthetic rubber output dropped 50 percent between 1945 and 1949 (from 1.90 billion pounds to 0.95 billion pounds) as this country converted from a wartime to a peacetime economy.

Undoubtedly, the extremely rapid early rate of economic growth of the synthetic rubber industry was more largely a result of the Government's creation of an artificial demand for synthetic rubber than from its investment in research and development and in production plants and facilities. Without this artificial market, it is likely that the Government's investments in technological development and manufacturing capability would have had only a limited impact on the economic growth of the industry. Therefore, probably the most effective technique available to the Federal Government to accelerate the rate of development and diffusion of technological innovations is to subsidize the market rather than research and development.

A comparison of the rate of commercial development of synthetic fibers and synthetic resins also provides an interesting insight into the process of the diffusion of technological innovations. As indicated in exhibit 12, the synthetic resin industry required 26 years from the start of commercial production to reach a level of output of $50

EXHIBIT 11. THE ECONOMIC GROWTH OF MAJOR TECHNOLOGICAL INNOVATIONS IN THE FIELD OF SYNTHETIC MATERIALS

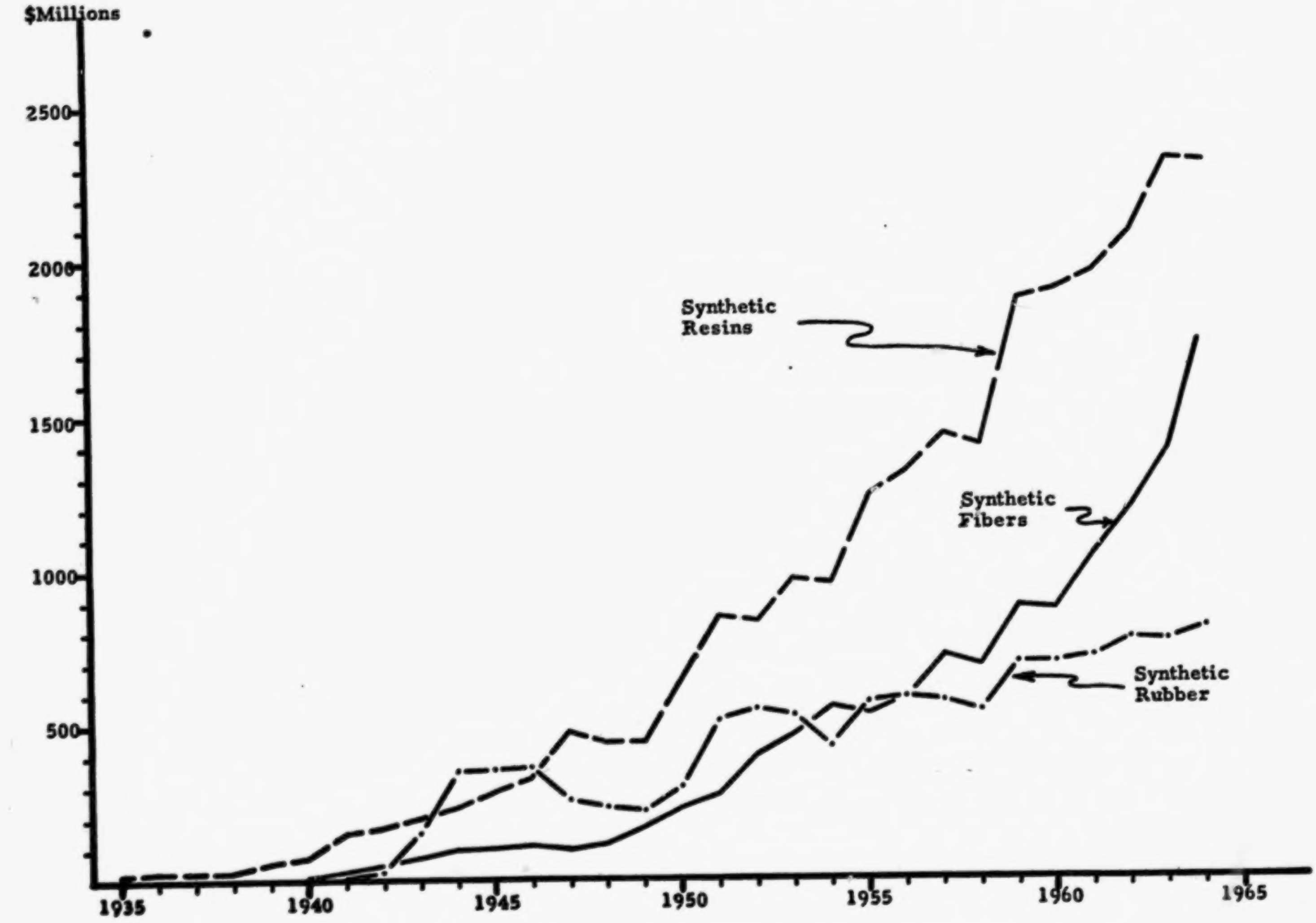


EXHIBIT 12. COMPARATIVE RATES OF COMMERCIAL GROWTH FOR THE SYNTHETIC FIBER, RUBBER, AND RESIN INDUSTRIES

Criteria for evaluation	Lapsed time from commercial introduction (years)		
	Synthetic fibers	Synthetic rubber	Synthetic resins
Date of commercial introduction	1939	1940	1910
Absolute economic criteria in million dollar output: [1]			
50	2	2−	26
100	3	2+	29
250	11	3	31
500	14	11	36
750	19	22	41
1,000	22	>24	43
Relative economic criteria in percent of GNP:			
0.02	1	1	<25
0.05	2	2+	29
0.10	13	2+	31
0.15	15	3+	36
0.20	22	3+	37
0.25	25	3+	41
0.50	>25	>24	>55

[1] Adjusted to the 1957–59 index of wholesale prices.

million per year; the first synthetic fiber achieved the same result in 1.6 years. The primary difference that appears to account for these extreme variations in the rates of commercial growth is application. Synthetic fibers had direct applications in consumer markets for clothing and women's hosiery, whereas synthetic resins initially had limited use in industrial markets, such as paints, varnishes, and textile coatings. The very rapid rate of commercial growth for synthetic resins did not occur until these materials began to find uses in toys, appliances, and other consumer applications.

The relative growth rates (as a percent of gross national product) for these three innovations in the synthetic materials field (exhibit 12) provide an even more graphic illustration of the importance of the market applications to the rate of commercial growth. Since the market for synthetic rubber was virtually unlimited because of wartime demands, synthetic rubber was able to attain a level of 0.25 percent of GNP in less than 4 years. Because the market for synthetic fibers was more restricted by the fact that it had to compete with silk, wool, and other natural materials, the rate of commercial growth was considerably slower—reaching 0.25 percent of GNP in 24 years. The commercial growth of synthetic resins was inhibited by the fact that its initial market was new and in industrial applications; broader areas of application had to be created before rapid commercial growth could occur. The result was that it required 41 years to reach a level of output of 0.25 percent of GNP, but the latter stages of this growth were at a rate faster than that of synthetic fibers—6 years to grow from 0.10 to 0.25 percent of GNP for synthetic resins versus 9 years for synthetic fibers.

3. Major Technological Innovations in the Field of Light Metals

The field of light metals—aluminum, magnesium, and titanium—provides an interesting insight into the process of technological innovation. These three metals are among the four most plentiful metallic elements on earth (iron is the fourth) and have a number of important physical and economic characteristics in common:

> **Each has a high strength-to-weight ratio and has valuable corrosion resistance properties.**
>
> **The separation of the pure metals from their natural ores involves costly electrolytic refining processes.**
>
> **Their commercial application had to await technological advances first in ore processing and later in alloy development and fabrication techniques.**
>
> **The commercial growth of each was fostered by technological advances in the field of military aviation.**

It is difficult to evaluate accurately the contribution which these light metals have made to our economy. Certainly none of them could be considered as basic an element of our economy and our way of life as steel or copper. On the other hand, they have truly made important contributions to the technological advancement of the field of aviation. In fact, it is unlikely that modern, high-speed civilian and military jet aircraft would be feasible if it were not for the aluminum, magnesium, and titanium alloys used in them. Also, the inroads which aluminum has made in some traditional applications for iron and steel (e.g., the automotive and container industries) and the slowly growing use of titanium in the chemical processing industry makes it evident that these metals do have a niche outside military and aerospace applications where their light weight is far more important than their high cost.

One other interesting aspect of this field as far as this investigation is concerned is that each of these light metals was introduced commercially approximately 30 to 40 years apart, thus permitting a direct comparison of the rate of technological development and diffusion during different time periods. Furthermore, two of these innovations, aluminum and magnesium, were largely developed by private initiative with a single company maintaining virtual monopolistic control over the innovation during most of its early economic development and growth. The situation was exactly the opposite in the case of titanium, with most of the commercial research and development done by the Federal Government and a primary market for this material created by military jet aircraft applications during the Korean war. Thus, the field of light metals also provides another opportunity to compare the rate of technological development and diffusion between publicly and privately financed innovations.

Aluminum

The technological history of aluminum began with the discovery of the metal 140 years ago (see exhibit 13). Twenty years later, a sufficient quantity of metal was produced to enable scientists to determine some of its physical and chemical properties. In 1954 two processes for removing the metal from the ore were developed—one produced aluminum by a chemical technique and was used until about 1890 but proved to be too expensive ($15 per pound) for commercial use. The other involved an electrolytic process but was technically impractical because at that time batteries were the only available source of electrical power. At this point, most of the technological discovery and development work on aluminum was done in Europe; but most of the subsequent research and development work occurred in the United States.

For approximately the next 30 years, aluminum technology remained dormant because of the lack of low-cost electrical power for the reduction of aluminum ore (bauxite) to metallic aluminum. This obstacle was gradually diminished during that period by Edison's work on electric power generation and the establishment of a direct current electrical power distribution system in the U.S. in 1882. The availability of low-cost electrical power in large quantities was the key to the commercial production of aluminum, and in 1886, Hall in the U.S. and Heroult, independently, in France developed the electrolytic process that is still used in the production of primary aluminum.

Although continual improvements have been made in raw metal production processes over the years to reduce operating costs, at that point, technological research and development efforts have sharply shifted to the development of new aluminum alloys and fabrication techniques which extended the applications and expanded the markets for aluminum. The aluminum industry's growth required producers and users of the metal to assem-

EXHIBIT 13. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF ALUMINUM

Basic Research and Investigation:
1825: Oersted first produced pure aluminum metal.
1827: Wohler produced aluminum as a powder.

Incubation Period:
1845: Wohler succeeded in producing a sufficient quantity of the metal to determine some of its properties.
1854: Deville established the basis for the first commercial production process.
1854: Bunsen showed that aluminum could be produced by an electrolytic process, but the process was impractical at the time because batteries were the only source of electricity.
1882: Edison's generator improvements and direct current distribution system fostered commercial development of low-cost electric power.

Commercial Development:
1886: Hall and Heroult independently discovered the production process (electrolytic reduction of aluminum) still used in the industry.
1888: The Pittsburgh Reduction Co. (later to become the Aluminum Corp. of America) was formed to produce aluminum.

Commercial Growth:
1892: Alcoa began commercial production of aluminum.
1915: Wartime effort intensified development work on alloys and new applications for aluminum.
1928: Reynolds Metals Co. was formed and acquired assets of an aluminum fabricator.
1938: Aluminum was used for almost all structural parts of military and larger civilian aircraft.
1940: Alcoa doubled capacity in this country by building and operating Government-owned reduction plants.
1946: Kaiser Aluminum & Chemical Co. was formed and acquired three reduction plants from the Government.
1946: Reynolds Metals acquired the remainder of the Government's aluminum plants.
1950: The Government encouraged expansion of capacity with construction loans, fast writeoffs, and guaranteed purchases for stockpile, resulting in new primary producers entering the industry and nearly doubled capacity in 4 years.
1965: Primary producers emulated Alcoa's example by integrating forward into fabrication.

ble a knowledge of the physical and chemical properties of various aluminum alloys equal to that which had accumulated in the iron and steel industry over a period of 2,000 years or more. The primary objective of this research effort was to improve the strength and corrosion resistance of the pure metal and to make fabrication of these metal alloys less costly.

Applications research and development efforts were principally privately sponsored and, until World War II, largely controlled by the only domestic producer of primary aluminum—the Aluminum Company of America. Gradually an aluminum alloy technology evolved that enlarged the applications for the metal. For example:

> During World War I, aluminum was used for pistons in internal combustion engines.
>
> An important new forging alloy was developed during the 1920's.
>
> In 1926, aluminum-clad sheet was available commercially.
>
> By 1938, most structural parts of military aircraft were made from aluminum.
>
> After World War II, aluminum foil came into widespread use.
>
> More recently, aluminum cans have displaced "tin cans" in certain food and beverage containers.

The fundamental economic fact underlying the growth of the aluminum industry is the need that existed for this metal in consumer and industrial applications as well as for military and aerospace uses. For example, kitchen utensils such as pots and pans of iron were too heavy to be fully satisfactory, but aluminum was strong enough to do the job and weighed only one-third as much. Not only did many needs exist for aluminum, but countless other uses were created as alloys were devised for various potential applications. Nevertheless, except for sharp peaks during World Wars I and II, growth of the aluminum industry was very slow and undramatic.

The economic circumstances that prevailed during the 60 years from 1888 (when Alcoa was incorporated as Pittsburgh Reduction Company) until the end of World War II greatly influenced the development and growth of the industry. Alcoa was the industry during that period, holding the basic Hall patent, having exclusive contracts with sources of bauxite, and being financed and guided by the Mellon banking interests of Pittsburgh. Several attempts by other companies to enter the industry failed. In 1928, Alcoa sired Aluminium, Ltd., and transferred to it all of Alcoa's foreign properties. Aluminium, Ltd. is now the biggest primary aluminum producer in the world.

The period after the end of World War II saw the emergence of aluminum as a major industry. In 1946, Reynolds Metals Co. and Kaiser Aluminum & Chemical Co. entered the field by purchasing the Government-owned aluminum plants built during World War II. During the next 17 years, the output of the aluminum industry increased sixfold. This rapid growth is partly attributable to natural growth of aluminum-dependent industries, such as commercial aviation, and partly to increased military usage. However, most of it has resulted principally from aggressive promotion of the metal in new applications such as automobile manufacture, residential and commercial construction, truck and rail transportation, and packaging.

Magnesium

Just as production of primary aluminum is miniscule compared to that of steel, domestic production of primary magnesium is equally small as compared to that of aluminum—about 3 percent. Yet, there are striking similarities in their histories. Magnesium, the third most abundant metal in the earth's crust (following aluminum and iron), was discovered 17 years before aluminum (see exhibit 14). Bunsen devised an electrolytic process to produce magnesium in 1852, 2 years before he developed a similar process for aluminum. The year the Hall-Heroult electrolytic process for aluminum reduction was developed (1886), two German scientists improved Bunsen's magnesium reduction process. At this point, the development paths of these two materials separated. Aluminum was marketed commercially in 1892, but it was 1909 before the first magnesium alloys were commercially available.

There is an interesting facet of the almost parallel development of these two light metals: if more research had been done on magnesium alloys during the early 1900's, the subsequent roles of the two metals might have been reversed. Magnesium is two-thirds the weight of aluminum, nearly as strong, produced by a similar process, nearly as abundant, and production costs are almost comparable. It is the easiest of the light metals to machine and its applications are very similar to those of aluminum. The primary difference between the two is that magnesium powder will ignite spontaneously in air and will burn intensely, a characteristic which certainly hindered research work on fabrication technology. Nevertheless, it may be a fluke of history that aluminum rather than magnesium has come to dominate the light metals industry.

EXHIBIT 14. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF MAGNESIUM

Basic Research and Investigation:

1808: Davy isolated metallic magnesium.
1828: Bussy prepared nearly pure magnesium.

Incubation Period:

1833: Faraday was first to succeed in producing metallic magnesium by electrolysis.
1852: Bunsen produced magnesium with a different type of electrolytic cell.
1857: Deville and Caron produced magnesium by using sodium to reduce magnesium chloride.

Commercial Development:

1886: Fischer and Graetzel further developed the electrolytic process.
1909: The first commercial magnesium alloys were marketed by a German firm.
1915: German domination of world trade in the industry was interrupted by World War I.

Commercial Growth:

1918: Dow Chemical Co. joined four other firms to start the magnesium industry in this country.
1927: Dow was the only domestic company left producing magnesium, with a capacity of about 2,500 tons per year.
1928: The carbothermic process for reducing magnesium was invented in Austria by Hansgirg.
1932: Alcoa and I. G. Farben Co. pooled magnesium production and fabrication patents and brought Dow into the cross-licensing agreement.
1940: Britain and United States discovered the widespread use of magnesium in German aircraft.
1940: The Federal Government authorized construction of 14 new magnesium plants, using 4 new reduction processes.
1941: An antitrust suit was brought against Alcoa and Dow by the Federal Government.
1942: Alcoa and Dow signed consent decrees promising not to monopolize the magnesium industry, and the Justice Department demanded that all patents be made available, royalty-free, for the duration of World War II.
1944: The magnesium industry capacity reached 295,000 tons per year with 10 of the 12 production plants owned by the Federal Government.
1946: Production fell to 5,300 tons causing several magnesium producers to quit the field.
1965: The magnesium industry in this country is comprised of four companies.

The early commercial development and exploitation of magnesium was carried out by German companies which dominated world trade in the metal until World War I. The advent of World War I disrupted German trade in magnesium, intensified domestic demand for both incendiary and aircraft structural applications, nullified German patents, and fostered the birth of the magnesium industry in the U.S. First commercial production was initiated in this country in 1918, but demand fell just as abruptly after the war leaving Dow Chemical Co. the only domestic firm in the industry until after World War II.

Technologically and economically, magnesium was born "second best" in the light metals field. Not only did it have to compete with aluminum as well as steel for markets, but to Dow, the only domestic producer, magnesium was only one of several products obtained from carefully balanced brine operations which also produced important chemical salts. Commercial development between the wars was hindered also by metallurgical engineering mistakes (e.g., the use of a self-destroying magnesium-copper alloy in automotive pistons) and by failures due to improper fabrication techniques. Furthermore, in 1932, Alcoa and I. G. Farben Co. negotiated a cross-licensing agreement on magnesium production and fabrication patents. Dow Chemical Co. was added later to the agreement, which endured until Federal antitrust action ended it in 1942. Thus, from 1918, the start of production in this country, magnesium required 15 years to approach aluminum in price, 20 years to reach an annual production rate of 2,400 tons, and 22 years to attain a permanent multicompany industry status.

In contrast, Germany had developed magnesium technology and commercial applications to where it was consuming 6 times as much of this metal as the U.S. The German Ford plant made extensive use of magnesium in cars, and German military aircraft contained as much as 1,000 pounds of this light metal. During the early years of World War II, the Federal Government authorized construction of 14 magnesium plants (only 2 privately owned) to be run by 12 private companies and using various processes to produce magnesium.

At the end of World War II, production dropped sharply, but magnesium began to expand its military aircraft applications. The industry is now operating at 10 times immediate postwar output levels with 4 companies now in the industry. However, less than 40 percent of current domestic consumption is used in primary structural applications with the remainder, ironically, being consumed in the production of other metals, principally as an alloying agent to improve the properties of its rival light metals, aluminum, and titanium.

Titanium

Titanium is the newest of the light metals and is now growing rapidly, primarily as a result of intensive Government interest in it for aerospace applications. It is the fourth most abundant metal in the earth's crust and is widely distributed; it has the strength of high quality steels but weighs only 56 percent as much, and has excellent resistance to corrosion and maintains its strength at higher temperatures than any other metal. Perhaps its most important property is its ability to be alloyed with most other metals and with many nonmetals to produce materials with a wide variety of characteristics.

Although titanium was discovered as early as 1789 (see exhibit 15), it was not until 1936 that a production process was devised. The U.S. Bureau of Mines perfected the process, which achieved success on a pilot plant scale in 1946. Commercial use of titanium began in 1950 in jet aircraft applications which capitalized on the material's strength and relative light weight. Because of titanium's potential advantages in military applications, the Office of Defense Mobilization fostered establishment of the titanium industry in 1951 with the granting of construction loans, fast write-off provisions, and purchase contracts for stockpiling the metal. In 1955, the Department of Defense established a titanium research laboratory and a central facility for collecting and disseminating information on titanium metallurgy, fabrication, and application technology. This intensive technical support by the Federal Government resulted in a gradual surmounting of the difficulties of fabrication, and now titanium can be machined nearly as easily as stainless steel.

The structural advantages of titanium led to its early uses in military aircraft, most civilian jet aircraft, and nearly all missiles. Titanium's ability to retain its strength at extremely high temperatures made it extremely useful in jet engines and as a structural material in supersonic aircraft, such as the A-11, X-15, TFX, and XB-70A, and the yet to be designed mach 3 transport. Titanium's corrosion resistance has also led to a U.S. Navy contract for an experimental submarine hull, and is rapidly opening industrial markets in such applications as corrosive petrochemical processes, paper bleaching, and heat exchangers.

EXHIBIT 15. CHRONOLOGY OF THE DISCOVERY AND DEVELMENT OF TITANIUM

Basic Research and Investigation:
  1789: Gregor discovered titanium.
Incubation Period:
  1910: Hunter isolated metallic titanium by reducing titanium tetrochloride with sodium.
Commercial Development:
  1936: Kroll developed a production process that involved the reduction of titanium tetrochloride with molten magnesium.
  1946: The U.S. Bureau of Mines succeeded in producing titanium on a pilot plant scale using Kroll's process.
Commercial Growth:
  1950: Titanium Metals Corp. of America was formed by Alleghany Ludlum Steel Co. and National Lead Co., and the first commercial production of titanium was begun.
  1951: The Office of Defense Mobilization fostered the growth of the titanium industry with construction loans, fast writeoffs, and purchase of output for strategic stockpiles.
  1955: Department of Defense established a titanium research laboratory and central facility for collection and dissemination of information on titanium characteristics, applications, and engineering.
  1957: The Federal Government stopped purchasing titanium for stockpile when the Department of Defense decided to base deterrent force on missiles instead of planes, thereby causing some producers to withdraw from the field.
  1962: Shipments of fabricated titanium exceeded previous peak volume (in 1957), with the metal being used in civilian and military craft, missiles, and some petrochemical processing equipment.
  1964: The newest military jet aircraft, the A-11, is said to represent "mastery of the metallurgy and fabrication technology of titanium metal."
  1965: The proposed U.S. design of a mach 3 supersonic transport plane would require extensive use of titanium to withstand the high temperatures generated by air flows at that high speed.

Another consideration that may have an important influence upon the growth of the titanium industry in the future is the present structure of the industry itself. There are presently three companies producing primary titanium into finished bars, sheets, and plates. Most of the companies in the titanium field were formed as joint ventures among some of the country's leading steel and chemical companies (e.g., U.S. Steel, Du Pont, Republic Steel, National Distillers), and thus have access to large financial resources to invest in additional research and development work on new applications for this newest light metal.

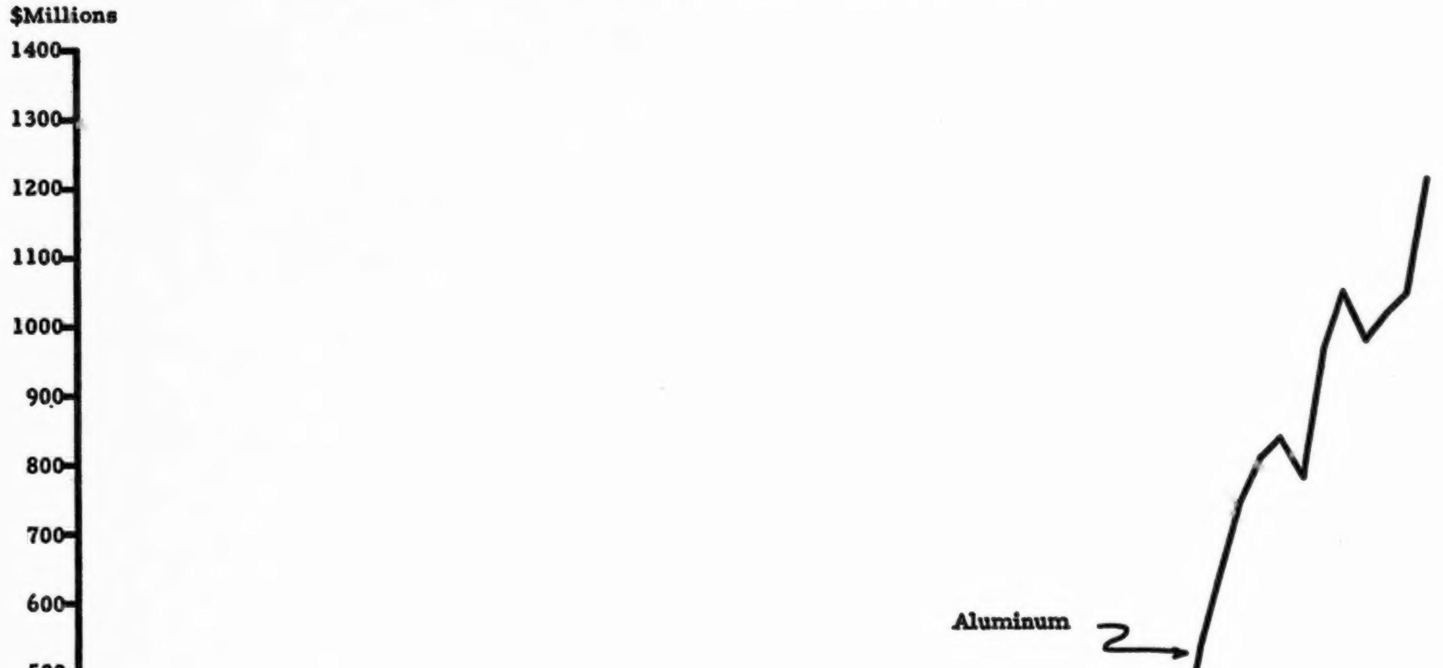
Conclusions

As indicated above, the level of output of the magnesium and titanium industries is small in comparison to the output of the aluminum industry—in 1964, aluminum output amounted to $1.21 billion versus an output of $57.0 million for magnesium and $20.8 million for titanium. Because of this wide disparity, it is difficult to make any extensive comparison of the rate of economic growth of these individual innovations in the field of light metals. Nevertheless, they provide an opportunity to gain an insight into changes in the early stages of commercial growth.

Exhibit 16 provides a graphic picture of the economic growth of these three innovations during the last 65 years. It also demonstrates another consideration that makes a meaningful analysis of the economic growth and development of these innovations even more difficult—the impact of an artificial demand created by wartime conditions. The output of each of these light metals reacted sharply to military requirements of World War I (for aluminum), World War II (for aluminum and magnesium), and the Korean war. The output of these critical light metals has also been inflated in recent years as a result of the Federal Government's efforts to stockpile them and the continuing high level of military expenditures.

In the light of these conditions, the rate of economic growth of these three innovations was analyzed in terms of both relative (various percentages of gross national product) and absolute (various dollar-value levels of output) economic measures. Results are shown in exhibit 17 which indicates that both aluminum and magnesium experienced a very slow rate of economic growth (as measured by both economic measures), with magnesium having an even slower rate of economic growth during the initial stages of its commercial application.

EXHIBIT 16. ECONOMIC GROWTH OF TECHNOLOGICAL INNOVATIONS IN THE FIELD OF LIGHT METALS



Another aspect of this analysis is the economic growth rate of titanium as compared to that of the other two light metals. The rate of growth for titanium during the early stages is approximately 5 to 6 times as fast as that of aluminum as measured by absolute levels of output, and approximately 3 times as fast when measured by relative economic criteria. However, because of Government stockpiling purchases, this early growth rate is misleading, and as the titanium industry continues to expand in the future, its overall rate of economic growth will probably not maintain this margin but will more closely approximate that of aluminum and magnesium.

EXHIBIT 17. ANALYSIS OF THE RATE OF ECONOMIC GROWTH IN THE FIELD OF THE LIGHT METALS

Criteria for evaluation	Lapsed time (in years) from introduction		
	Aluminum	Magnesium	Titanium
Start of commercial production	1892	1918	1950
Absolute measure in $ million output:[1]			
25	14	24	3
50	23	25	4
100	24	25	>14
Relative measure in percent of GNP:			
0.01	10	24	4
0.02	14	25	6
0.05	23	>46	>14

[1] In constant dollars based on 1957–59 index of wholesale prices.

4. Major Technological Innovations in the Field of Communications

Two technological innovations in the field of communication—radio and television—are apt subjects for this investigation since these must rank among the most significant technological innovations of the 20th century. Although both radio and television are often maligned publicly and privately (e.g., "television's vast wasteland"), in all honesty these two innovations must be acknowledged as having had an important impact on our economy and way of life.

The ability to reach large segments of our population has made radio and television broadcasting a medium of mass communication without equal in our society. This mass communication capability is further enhanced by a unique ability to provide information, education, and entertainment to individuals of all ages and social and economic levels. One cannot help but be awed by the potential of radio and television to inform and educate as young children discuss rocket launchings, spacecraft, orbiting, and reentry in the same breadth as the latest episode of "Lassie." As satellite communication systems are developed and placed in commercial operation, radio and television will truly become a worldwide medium of mass communication, and are likely to have important effects on all nations of the world.

The contribution of radio and television broadcasting to this country's economy has been equally as significant as the social and cultural changes these innovations have produced. In 1964, the output of the radio and television industry (including both broadcasting and the manufacture of radio and television receiving sets) exceeded $4 billion, and has been increasing at a rate of approximately 10 percent per year during the last 3 years.

Although the direct economic contribution of the radio and television industry has been substantial, its most significant contribution has been its overall impact on our consumer economy. As a unique medium of mass communication capable of reaching individuals of all ages and social and economic levels, radio and television provide manufacturers of consumer goods with unequalled opportunities to bring the merits of their particular products to the attention of large segments of the population. Furthermore, by choosing broadcasting time, a company can selectively determine the segment to which its products will be exposed. It is quite evident that most of our consumer goods industries could not have attained their present levels of output were it not for the radio and television industries.

Radio Broadcasting

The development of wireless communications (radio) presents an interesting example of how social and economic conditions can transmute a basic technology and drastically alter its original purpose and application. When initially developed in the late 1890's and early 1900's, radio was conceived as simply an extension of existing private wire communication services (telephone and telegraph). Thus radio was viewed as a method of extending telephone and telegraph service to ships at sea, remote geographical locations, or other places that could not be reached directly by wire communications. As a result, most of the original research on the development of wireless communication was initially oriented toward the relatively simple task of transmitting impulses for telegraphic communications (see exhibit 18). Much of this early development work was done by Marconi in England, and by the start of World War I, commercial telegraphy was an established industry.

The first successful experimental voice transmission was made by Fessenden in 1900, followed 6 years later by his first successful long-distance radio voice transmission establishing radio's technical feasibility. Despite this early success, the evolution of radio from the laboratory stage to a commercial development had to await two other technological advances in the field of electronic circuitry—the development of the triode by DeForest in 1907, and the regenerative circuit by Armstrong in 1913.

Further impetus to the development of radio was provided by the establishment of Radio Corp. of America in 1919, an event of particular importance to the development and growth of the radio industry. RCA was established to consolidate the patent holdings of the major American companies in the wireless transmission field (American Marconi Co., American Telephone & Telegraph Co., General Electric Co., and subsequently, Westinghouse Corp.), and to cross-license these patents among these companies. Prior to this time, it was virtually impossible for any company to manufacture an effective radio transmitter or receiver without infringing on another's patents. At the time of its establishment, RCA held over

Exhibit 18. Chronology of Discovery and Development in Radio Broadcasting

Basic Research and Investigation:

1837: Morse invented the electric telegraph.
1873: Maxwell published a treatise that first presented the theory of electromagnetic energy.
1876: Bell developed and patented the telephone.
1878: Hughes devised the first carbon microphone.
1888: Herts confirmed Maxwell's theories on wireless transmission by sending and receiving radio waves.

Incubation Period:

1896: Marconi was issued the first patents on wireless transmission in England.
1897: Marconi developed the first spark-coil transmitter and established a company in England to exploit its commercial applications.
1898: Lodge invented and patented a method of selective tuning for wireless communications.
1900: Fessenden made the first successful experimental radio broadcast.
1901: Marconi transmitted the first wireless telegraph message across the Atlantic.
1906: Fessenden made the first long-distance radio broadcast and demonstrated the technical feasibility of radio.
1907: DeForest developed the 3-element (triode) vacuum tube.
1908: DeForest broadcast phonograph music from the top of the Eiffel Tower.

Commercial Development:

1913: Armstrong developed the regenerative radio circuit.
1919: Radio Corp. of America was established and subsequently arranged cross-licensing agreements on radio patents with American Telephone & Telegraph Co., General Electric Co., and Westinghouse Co.
1920: Station KDKA in Pittsburgh became the first commercially licensed radio station and transmitted the results of the Harding-Cox presidential election.
1920: Armstrong invented the superheterodyne radio circuit.

Commercial Growth:

1922: Station WEAF began broadcasting in the New York area, and the first "commercial" was broadcast.
1923: The first network broadcast between New York City and Dartmouth, Mass., was initiated.
1924: The first coast-to-coast radio broadcast was made of a speech by President Coolidge.
1926: American Telephone & Telegraph Co. withdrew from the field of radio broadcasting.
1926: The National Broadcasting Co. was formed and went into operation.
1927: The Federal Radio Commission (now the Federal Communications Commission) was established by Congress to regulate the field of radio broadcasting.
1927: The Columbia Broadcasting System was established.
1932: An antitrust suit by the Federal Government resulted in the divesture of the Westinghouse and General Electric interests in RCA.
1933: Armstrong developed a practical system of frequency modulation (FM) broadcasting.
1938: Experimental FM broadcasting was started.
1941: First commercial FM broadcasting was inaugurated.
1945: Manufacture of radios was resumed.
1954: Radio was displaced by television as the primary source of broadcasting revenue.

2,000 patents in the field of radio, including virtually all that were of importance at that time.

As mentioned above, the transmutation of radio from a vehicle for private communication to one of public communication for use by anyone was an evolutionary process. The initial step was the establishment of station KDKA in Pittsburgh as the first commercial radio station (in 1920) with the broadcasting of the results of the Harding-Cox Presidential election. The first 2 years of radio broadcasting were largely limited to this type of news and information reporting.

The first "commercial" radio broadcast originated from station WEAW in the New York area in 1922, marking the beginning of the radio broadcasting industry. In 1923, the first radio network broadcast was made from New York City to Dartmouth, Mass., and was followed by the first coast-to-coast radio broadcast, of a speech by President Coolidge. During this period, the number of licensed radio broadcasting stations increased from 30 in 1922 to more than 500 in 1924.

The following 5 years were a period of very rapid growth for the radio industry, accompanied by the consolidation that seems to be inevitable in every new industry. During this time, the NBC and CBS broadcasting networks were established, and they acquired a number of independent radio stations; A.T. & T. withdrew from broadcasting to devote its efforts to the field of telephone communications, and the Federal Radio Commission (now the Federal Communications Commission) was established to regulate the entire field of public communications.

The most significant technical and economic developments from 1930 to the present was the development and commercial introduction of television and FM broadcasting. Although television quickly displaced radio as the primary medium of mass communication, both these developments provided the impetus that has enabled the commercial broadcasting field to reach its present level of output of more than $4 billion.

Television Broadcasting

The most surprising aspect of the development and growth of the television industry is its long history of research and technical developments. Initial research in this field paralleled that of radio, both in time and in scope. The basic technical feasibility of television was established in 1907 (see exhibit 19), the same year that DeForest developed the 3-element vacuum tube which proved to be the key technical development in the field of radio.

The next 15 years in the history of television were primarily ones of technical frustration. There was a common expectation in the radio industry during the 1920's that the technical problems of television would be resolved quickly and that commercial television broadcasting would soon follow in the wake of radio broadcasting. The reason for this optimism was that while the technology of television receiving sets was considerably more complex than that of radio receiving sets, the two were very similar.

EXHIBIT 19. CHRONOLOGY OF DISCOVERY AND DEVELOPMENT IN TELEVISION BROADCASTING

Basic Research and Investigation:

1862: Caselli developed a crude system of phototelegraphy capable of long-distance image transmission.

1875: Carey designed a crude television system utilizing selenium cells.

1878: Crooks developed the cathode-ray vacuum tube.

1884: Nipkov developed a mechanical scanning system suitable for transmitting stationary images.

1897: Braun developed the cathode-ray oscilloscope by adding a fluorescent screen to a cathode-ray vacuum tube and controlling the path of the electron beam with electromagnets.

Incubation Period:

1907: Rosen developed and patented a device for receiving television pictures from a nearby mechanical television transmitter.

1907: DeForest developed the 3-element (triode) vacuum tube.

1923: Zworykin patented an electronic camera tube embodying the basic concepts of electronic scanning.

1924: Bell Laboratories undertook a research program on mechanical television scanning systems.

1927: Bell Laboratories made the first long-distance television broadcast from Washington to New York using a mechanical scanning system.

1928: Zworykin developed a practical electronic scanning tube for television transmission.

Commercial Development:

1929: Bell Laboratories conducted a successful color television broadcast.

1930: Bell Laboratories established an experimental two-way television transmission system to A.T. & T.'s headquarters in New York City.

1935: RCA Laboratories developed a high-resolution television system similar to the one presently used.

1936: RCA constructed an experimental television transmitting station atop the Empire State Building and successfully transmitted pictures 45 miles.

1937: Seventeen experimental television stations were in operation.

1939: Dumont Co. manufactured the first commercial television set.

1939: The Milwaukee Journal filed the first application with the FCC for a commercial television broadcasting license.

1940: CBS publicly demonstrated a mechanical color television system.

1941: The FCC authorized the start of commercial television broadcasting on July 1, 1941.

1942: The manufacture of all television broadcasting and receiving equipment was suspended for the duration of World War II, with about 10,000 television sets in consumer use.

Commercial Growth:

1945: Production of consumer television receivers was resumed, and the FCC allocated 13 VHF channels for commercial television broadcasting.

1946: The FCC received the first petition for color television from CBS which was subsequently deferred until standards could be established.

1947: RCA announced development of a color television system that was compatible with black-and-white television broadcasting.

1948: The issuance of new television broadcasting permits was frozen pending further study of the television broadcasting industry.

1951: A.T. & T. completed a transcontinental microwave transmission system and coast-to-coast television broadcasting was inaugurated.

1953: Magnetic tape recording for television was developed.

1953: The FCC approved standards for color television.

1965: Color television became an important aspect of television broadcasting.

The primary technical deterrent to the commercial development of television during this innovation's 22-year incubation period was the method of image scanning utilized in transmitting the broadcast picture.

Early research on image scanning was concentrated on the development of mechanical systems. As early as 1927, Bell Laboratories made a successful television broadcast from Washington to New York utilizing a mechanical scanning system. By 1930, Bell Laboratories had made a successful color telecast and had established an experimental two-way television transmission system between New Jersey and New York City. However, the difficulties of maintaining synchronization between a mechanical transmitter and remote receiving sets made this technique unfeasible for consumer use.

The key technological innovation in the field of television from the commercial point of view was the development of an electronic scanning tube by Zworykin in 1928. Although this was the technical breakthrough needed to make television technically feasible for consumer use, a lengthy period of commercial development, particularly on picture quality, ensued before television could be released to the public. Experimental commercial telecasting began in 1936, and by the following year 17 experimental television stations were in operation.

The first application for a commercial television broadcasting license was made to the FCC in 1939 by the Milwaukee Journal. After approving television broadcasting standards, the FCC authorized the start of commercial television broadcasting operations by several stations on July 1, 1941. However, with the entry of the United States into World War II 5 months later, further production of television broadcasting equipment and receiving sets was suspended for the duration of the war. The industry remained in a state of limbo during that period with about 10,000 television sets in operation and only a limited amount of television broadcasting.

The true commercial growth of television did not begin until after the end of World War II, when all restrictions on manufacturing and broadcasting were removed. During the next 5 years, the growth of the industry was so rapid that it is difficult to comprehend, with the combined revenues from the manufacture of television sets and television broadcasting exceeding $1.5 billion during 1950. The television industry continued to grow steadily until the late 1950's when both television manufacturing output and broadcasting revenues began to stabilize. However, within the last 3 years growing consumer acceptance of color television has provided a substantial impetus to the industry's economic growth, which should continue for several more years.

Conclusions

This investigation of radio and television provides an opportunity to examine the rate of diffusion of technology in a consumer product field that is virtually without Government subsidy either in research or application. Furthermore, the rate of diffusion for a primary innovation (radio) which created an industry in the consumer field can be compared with that of a secondary innovation (television) in the same field which was able to build on a substantial foundation of people and facilities already in existence.

One difficulty inherent in any attempt to measure the rate of commercial development (diffusion) of the radio and television industries arises because they involve both a product and a service. The transmission of radio and television programs is primarily a service function which can only be measured in economic terms through revenues received for these broadcasts; yet the reception of this radio and television transmission can only be measured in economic terms by the value of the product (i.e., radio and television sets) used for this purpose by the consumer. Because neither the product nor the service can exist without the other, the rate of commercial growth of the two industries has been measured by combining the value of the output of television and radio manufacturing with the corresponding value of television and radio broadcasting revenues for the years under study. Although this method of measurement understates the true economic importance and growth of the two industries by excluding the value of the sales and service operations that are an important part of radio and television set manufacturing, it is reasonably consistent with the methods used to measure the rate of diffusion of other technological innovations.

The value of output for the radio and television industry is shown individually and in total in exhibit 20. A more detailed analysis and comparison of the rate of economic growth of these industries is presented in exhibit 21. The most significant fact revealed by these exhibits is the extremely rapid rate of commercial growth experienced by both industries during their early stages of development. In terms of absolute meas-

EXHIBIT 20. THE ECONOMIC GROWTH OF RADIO AND TELEVISION BROADCASTING

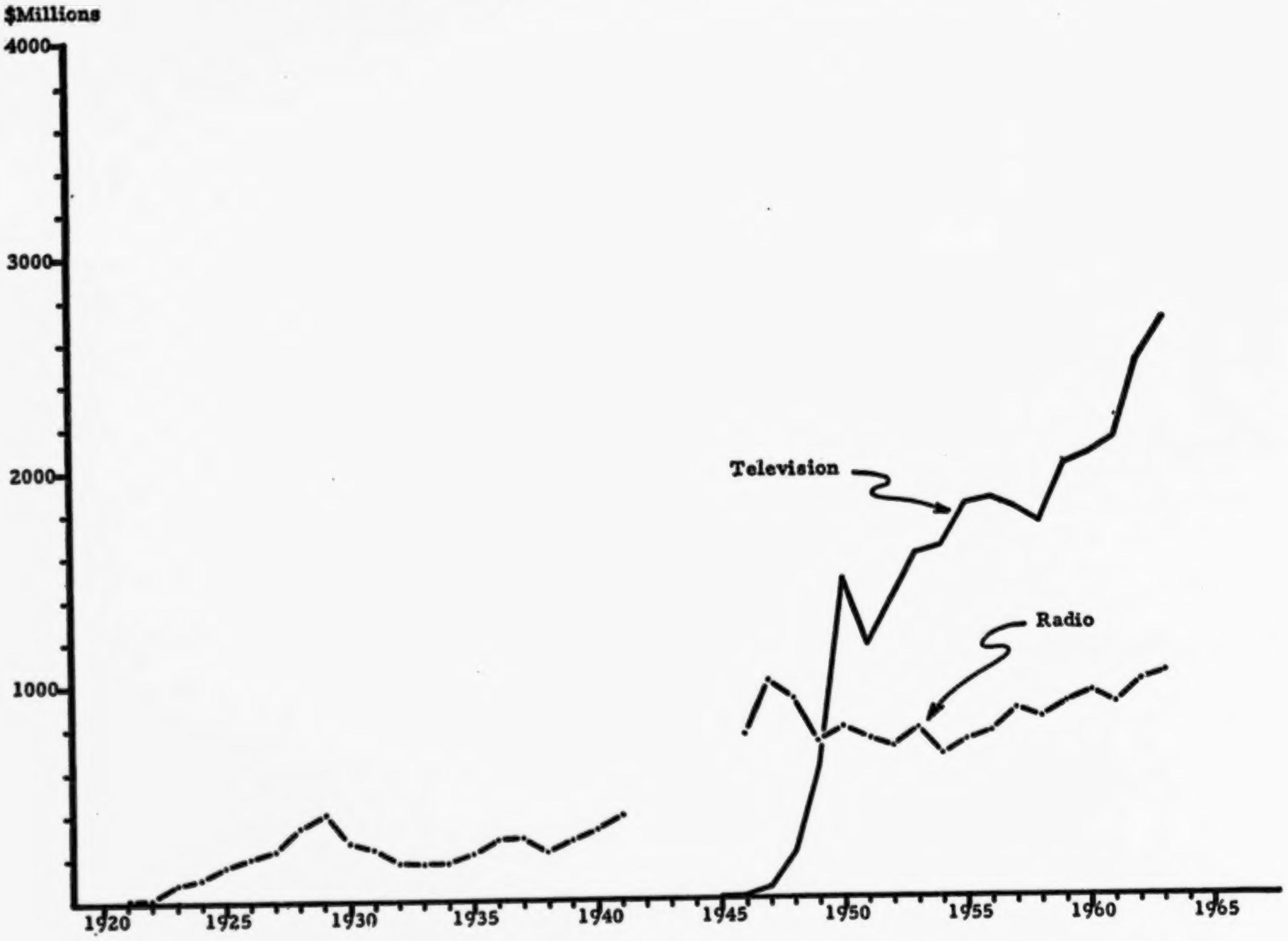


EXHIBIT 21. COMPARATIVE RATES OF ECONOMIC GROWTH FOR THE RADIO AND TELEVISION INDUSTRIES

Criteria for evaluation	Lapsed time from commercial introduction (years)	
	Radio	Television
Date of commercial introduction	1922	1945
Absolute economic criteria in $ million output: [1]		
50	2	2
100	3	2+
250	4	3
500	7	3+
750	8	4
1,000	21	4+
1,500	>42	5
Relative economic criteria in percent of GNP:		
0.10	3	3+
0.15	4	4−
0.20	6	4
0.25	7	4+
0.50	22	5
0.75	>42	19

[1] Adjusted to the 1957–59 index of wholesale prices.

ures, the radio industry was able to attain a level of output of $750 million in 8 years and television in about 4 years. As measured in relation to gross national product, a similar situation is evident, with the radio industry reaching a level of 0.25 percent of GNP in 7 years and the television industry reaching the same level in slightly more than 4 years. At that point, the rate of growth of the radio industry declined but continued for the television industry, reaching an almost unbelievable level of 1.5 billion (0.50 percent of GNP) within 5 years from the date of commercial introduction.

To some extent, the television industry's rapid growth can be attributed to the fact that much of the basic foundation upon which the industry was built (i.e., studio facilities, personnel, advertising agencies, appliance stores, etc.) was already in existence because of the radio industry. Radio did not have this foundation, and essentially had to create an entire new industry structure upon which to build. Yet the economic growth of this industry is impressive in comparison to most technological innovations.

The large amount of research and development is a factor which probably contributed significantly to the rapid growth of the radio industry. During the period of commercial development, a substantial portion of the funding for research and development was underwritten by private individuals in hopes of eventually earning a profit on their investment through the sale or licensing of resulting patents. Although most of these private investments were notably unsuccessful, they did provide a continuous flow of research funds during the critical phases of radio's technical development.

During the early period of the radio industry's growth, emphasis on research continued but the source of the funds changed. The four companies that dominated the radio industry from 1910 to 1930, American Telephone & Telegraph, General Electric, Radio Corp. of America, and Westinghouse, were all research oriented and invested substantial amounts of corporate funds in radio research and development. (A.T. & T. alone spent $21 million on direct radio research in a 15-year period, and an additional $25 million on closely related research.) This support of technical research was accompanied by even larger investments in exploiting the opportunities in radio, which undoubtedly further accelerated the commercial growth of the industry. The investment in both research and commercial development was possible because of the financial resources of the companies in the field. It is unlikely that the rate of technical and economic progress would have been nearly as rapid if a large number of small companies had dominated the radio industry.

The most significant conclusion that can be derived from this admittedly brief study of the commercial growth of these industries is the very rapid rate of diffusion possible for technological innovations with consumer application. The fact that a new-consumer industry (radio) can be created and reach a level of $750 million in 8 years, and that another innovation (television) introduced within an existing consumer industry can attain a level of $1.5 billion in 5 years suggests that the rate of diffusion of technological innovations in consumer product areas may be considerably greater than that for innovations in industrial product areas.

5. Major Technological Innovations in the Field of Food Preservation

Man has historically located his home according to the availability of food and water. He could travel only so long as he remained close to sources of both, and he was forced to move if the local supply of either vanished. To travel when neither was available, he had to provide means of taking them with him and keeping them in a usable condition. The voyages of Columbus and Magellan suggest that man had found adequate, if not entirely satisfactory, techniques for preserving food several hundred years ago.

Even the method of food preservation most widely used today, canning, is an old development—the process of preserving foods by heating in sealed metal and glass containers dates back to the early 19th century. The growth of the canning industry would be of interest to this study, but lack of economic data makes it unsuitable. This investigation, consequently, is focused on two more recent developments in the field of food processing, quick freezing and freeze drying. The former has already proven its commercial importance; the latter is beginning to demonstrate that it may have an important role to play in the field of food preservation in the future.

Frozen Foods

Freezing to preserve foods is an ancient practice with Eskimos and others in cooler climates, but the use of freezing commercially to preserve food did not materialize until the 20th century. The development of food freezing evolved from several distinct directions. Basic technological developments concerned with methods for producing subfreezing temperatures began with the 17th century discovery of a process to make artificial ice. Further advances were made during the 19th century when several patents were granted for food preservation processes involving immersion in ice and brine (see exhibit 22). However, the advent of mechanical refrigeration in the 1800's was the basic technological discovery that enabled the frozen food industry to become a commercial food preservation process. Mechanical refrigeration came into use for preserving boatloads of meat bound for England in the 1880's but it was the accidental freezing of one of those cargoes that led to the use of freezing as a commercial food preservation process.

The second major factor which contributed to the creation of the frozen food industry was the slow accumulation of a technology of freezing various foods to produce an acceptable consumer product. Until about 1900, work had been concentrated on the preservation of meats and fish. Gradually development efforts were extended to include fruits and vegetables, but progress was slow because different food products react differently to freezing. (The complexity of this is evident by the use of freezing equipment engineered to a specific type of food.) It was not until 1916 that the rate of freezing was recognized as the significant factor in maintaining the quality of frozen foods.

EXHIBIT 22. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF FROZEN FOODS

Incubation Period:

1842: Benjamin obtained an English patent for a process of preserving meats by freezing through immersion in ice and brine—one of several food freezing patents granted in the 19th century.

1880: Mechanical refrigeration, the basic foundation for today's food freezing industry, was used to preserve a boatload of meat transported from Australia to England; the unintentional freezing of one cargo led to the use of freezing as a standard practice.

1908: Baker, in Colorado, successfully froze fruits—one of the earliest attempts to broaden the scope of frozen foods beyond meats and fish.

Commercial Development:

1916: Three German researchers showed the benefit of quick freezing (hours rather than days) in preserving food quality.

1917: Clarence Birdseye began his investigations into frozen food, emphasizing development of methods of freezing foods in small containers suitable for purchase by the consumer.

Commercial Growth:

1925: General Seafoods Co., established by Birdseye, began production of frozen fish.

1927: The belt freezer was introduced, permitting production on a continuous basis.

1929: The first commercial frozen food pack was put on the market after considerable experimentation by General Foods Corp.

1937: Household freezers grew rapidly and provided the vehicle which brought frozen foods into the home on a widespread scale.

1946: The postwar period initiated new consumer interest in convenience foods. This combined with the ability to pay a premium for frozen foods and the introduction of freezers for home use to provide a great impetus to the growth of the frozen food industry.

1947: Overproduction and overestimation of consumer acceptance drove many producers from the industry.

1954: "TV dinners" were introduced and were the harbinger of a broad line of frozen food products marketed during the 1950's and 1960's.

Both mechanical refrigeration and the development of a technology set the stage for the introduction of frozen foods as a consumer product. For all practical purposes, the industry began in 1925 when Clarence Birdseye formed the General Seafoods Co. to produce frozen fish using a batch-type immersion process. Shortly thereafter, the belt freezer was introduced, continuous production became possible, and the General Foods Corp. began to offer a broader line of frozen foods.

From that point, the growth of the frozen food industry became dependent on other factors. Certainly the economic prosperity of the mid-1920's fostered the introduction of frozen foods since money was available for such luxury items as frozen foods. Correspondingly, the depression of the 1930's made higher frozen food prices unattractive to large segments of the consumer market. Moreover, very little refrigeration equipment was available to transport frozen foods, keep and display them in stores, and keep them frozen at home.

The advent of World War II provided an unexpected stimulus to the growth of the frozen food industry. Foods preserved by conventional canning processes had to be packaged in tin cans which were needed for military food supplies, but frozen foods could be packaged in less critical materials. Therefore, frozen foods were declared nonessential, with the result that the growth of the frozen foods industry was actually fostered by wartime restrictions on canned foods.

The post-World War II period witnessed the emergence of frozen foods as a major industry. Its growth was closely associated with the tremendous upsurge in consumer purchases of appliances, including refrigerators with freezer compartments, and increasing personal income which left more money in the food budget for the purchase of convenience foods. Despite the resulting prosperity, the post-World War II period was one of upheaval in the industry. The postwar boom was anticipated by so many producers that overproduction occurred, and eventually resulted in severe competition that forced about 200 producers out of the business.

The explosive growth of the industry was fostered by the advent of frozen orange juice, other concentrates, and various frozen prepared specialties which resulted in a thirteenfold expansion in the industry during the last 15 years. Although technological advances were made during that period (some as an outgrowth of cryogenic research associated with outer space exploration), it is noteworthy that the spectacular growth of frozen foods at that time is largely unrelated to the technology of food processing. Instead, the industry's growth is directly attributable to sustained economic prosperity, the variety and quality of the foods offered, and the enormous potential of the consumer food market.

Freeze-Dried Foods

Freeze drying is a method of preserving foods that combines the earlier known processes of freezing and dehydration. The basic technological concepts of freeze drying grew out of medical research on the preservation of blood. The primary impetus to the development of freeze drying was supplied by the Armed Forces' interest in foods made more readily transportable by eliminating water content. The need was revived during the Korean war but only modest results were obtained until 1955 when a new method was developed with considerable commercial promise (see exhibit 23).

EXHIBIT 23. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF FREEZE-DRIED FOODS

Basic Research and Investigation:

1940's: The principles of freeze drying were developed by medical research in the preservation of blood.

1940's: Freeze drying was sought as a means of making foods more easily transportable under wartime conditions by eliminating the water in foods.

Incubation Period:

1951: The Korean war revived the military need for more easily transportable food.

Commercial Development:

1955: A commercially promising method of freeze drying foods was developed.

Commercial Growth:

1961: Freeze-dried foods were introduced to the civilian market.

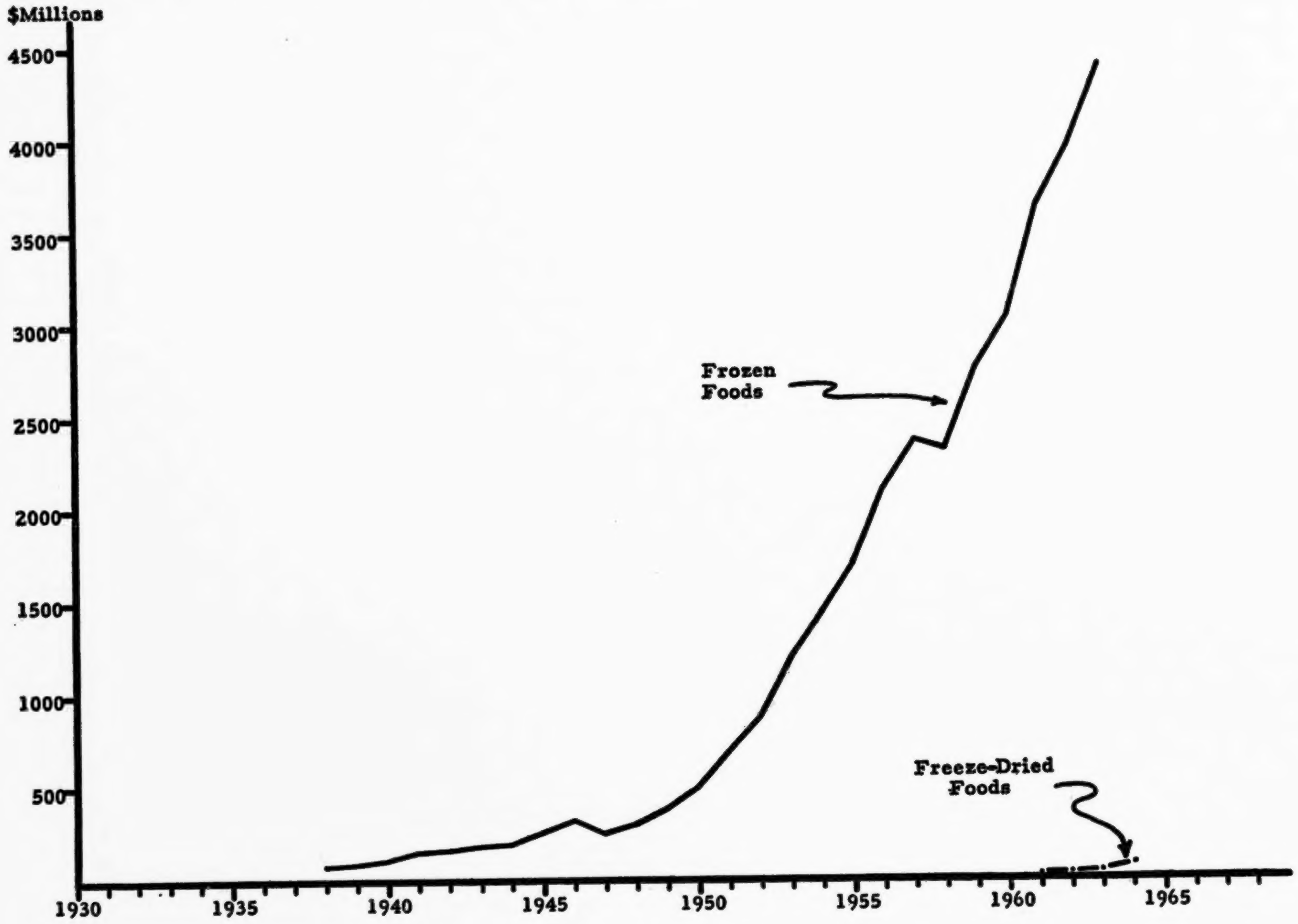
1965: Several food manufacturers introduced cereals that incorporated freeze-dried fruits in packages.

This method involved freezing the food, subjecting it to a vacuum, and then applying heat, which results in the sublimation of the water in it. In the absence of water, the natural deterioration of food ceases because all bacterial and enzymatic action is suspended. Freeze drying is applicable to a variety of foods; it preserves the nutritional constituents and has very little effect on the structure and size of the food, but it causes some detracting changes in appearance.

Since 1961, when freeze-dried foods were introduced to the consumer market, many producers have entered the field. For the most part, they are established firms in the food field, active in food research, and with access to substantial research funds—a necessity with freeze drying since the process is expensive in terms of facility requirements. An estimated 21 freeze-drying plants are now operating in North America, with others under construction.

The commercial growth of freeze-dried foods has closely paralleled that of frozen foods. Because the process is still relatively expensive in comparison to other methods of food preservation, its use has primarily been limited to such specialty items as mushrooms and foods for campers. The

EXHIBIT 24. ECONOMIC GROWTH OF INNOVATIONS IN THE FIELD OF FOOD PRESERVATIVES



first widespread use of freeze-dried foods for consumer application was in the preparation of certain soups. More recently, several food manufacturers have introduced new dry cereal products that contain freeze-dried fruits. The primary difference between freeze-dried foods and frozen foods is that no special refrigeration or other equipment is needed for freeze-dried foods either at the retail outlet or in the home; that they can be stored at room temperature should assist the commercial growth of freeze-dried foods in the future.

Conclusions

The history of the commercial growth of both frozen and freeze-dried foods is shown in exhibit 24, and a comparison of the relative and absolute growth for these innovations is summarized in exhibit 25. As indicated above, the commercial growth of frozen foods was relatively slow, requir-

EXHIBIT 25. COMPARISON OF THE RATE OF COMMERCIAL GROWTH FOR FROZEN AND FREEZE-DRIED FOODS

Criteria for evaluation	Lapsed time from commercial introduction (years)	
	Frozen foods	Freeze-dried foods
Date of commercial introduction	1925	1961
Relative economic criteria in percent of GNP:		
0.02	9	>4
0.05	12	------
0.10	15	------
0.15	21	------
0.20	26	------
0.25	27	------
0.50	31	------
0.75	38	------
1.00	>40	------
Absolute economic criteria in $ million output:[1]		
50	10	4
100	12	>4
250	15	------
500	25	------
750	26	------
1,000	27	------
1,500	29	------
2,000	31	------

[1] Adjusted to the 1957–59 index of wholesale prices.

ing 9 years to reach a level equal to 0.02 percent of GNP, and 26 years to attain 0.20 percent of GNP. This slow rate of growth was attributable to two factors—economic conditions during the 1930's, and the need for retail and consumer storage facilities for frozen foods. However, since attaining the 0.20-percent level, the frozen foods industry has grown very rapidly. Where it required 27 years for output to reach a level equal to 0.20 percent of GNP, only 5 more years were required to reach a level of 0.50 percent of GNP and an additional 7 years to reach 0.75 percent of GNP.

Unfortunately, the commercial growth of freeze-dried foods has not reached a point where comparisons of these rates of growth can be made. Freeze-dried foods did attain the lowest absolute economic level ($50 million) in 4 years versus 10 years for frozen foods, but because of the 36-year interval between the introduction of the two innovations, this comparison is somewhat meaningless.

6. Major Technological Innovations in the Pharmaceutical Field

The study of recent major technological innovations in the pharmaceutical field differs from the other portions of this investigation since the primary impact of pharmaceutical innovations has been more social than economic. Although the pharmaceutical industry is not an insignificant part of our industrial economy (industry output in 1964 exceeded $800 million), the social effects of pharmaceutical innovations have far outweighed this economic contribution. To a large extent, the present concern for the population explosion is a direct outgrowth of these technological innovations: Antibiotics have reduced death rates at all age levels and contributed to the ever-increasing lifespan of our population; furthermore, they have made important contributions to the general health and well-being of this country's population, resulting in such indirect benefits as greater overall labor productivity due to fewer illnesses and a reduction in lost working time by members of the labor force.

Two recent technological innovations in the pharmaceutical field are of particular interest to this investigation—vitamins and antibiotics. Not only have these two products made important contributions to the health of our country and of the world, but together they comprise the major portion of the output of the pharmaceutical industry. Antibiotics accounted for approximately 60 percent of total industry output in 1963, and vitamins an additional 12 percent.

Vitamins

Vitamins are organic compounds that are a minute but very essential part of everyone's diet. The existence and nature of vitamins was first demonstrated in a medical study of beriberi in 1897 (see exhibit 26). The next step in the discovery of vitamins occurred 15 years later, when scurvy was found to be a disease caused by vitamin deficiency. By 1927, it became clear that vitamins played an important health role as further research demonstrated a definite connection between vitamin deficiencies and such diseases as rickets, pellagra, and pernicious anemia. Most of the research during this 30-year period was concentrated on problems and diseases associated with dietary deficiencies, with only a limited effort to developing answers to these problems.

Exhibit 26. Chronology of the Discovery and Development of Vitamins

Basic Research and Investigation:
1897: Eikman induced beriberi in chickens, restored them to health by controlling their diet, and established the concept of deficiency diseases.
1912: Holst and Frohlich produced and cured scurvy in guinea pigs, thereby identifying foods containing antiscorbutic agents.

Incubation Period:
1913: The existence and effects of vitamin A were first recognized.
1918: Mellanby determined that a vitamin was the effective agent in cod liver oil that controlled rickets.
1922: Vitamin E was first identified by Evans and Bishop.
1924: Investigators determined that the salutary effects of sunlight on humans were due to formation of vitamin D in the body as a result of ultraviolet radiation.
1925: Goldberg demonstrated that pellagra was a deficiency disease.

Commercial Development:
1926: Jansen and Donath isolated Thiamine (vitamin B_1), the first vitamin obtained in pure form.
1927: Minot and Murphy discovered that pernicious anemia could be treated with large amounts of whole liver.
1930: Pure vitamin D was isolated by several groups in Germany and England.
1932: Ascorbic acid (vitamin C), the antiscurvy agent, was isolated.
1933: The chemical structure of vitamin A was established.
1933: Riboflavin was recognized as a vitamin (B_2).
1934: Dam induced hemorrhages in chickens through lack of vitamin K_1.
1936: Vitamin E was isolated in a pure form.

Commercial Growth:
1937: The approximate date when vitamin C, ascorbic acid, was introduced commercially.
1937: Nicotinic acid (Niacin) was identified as the vitamin involved in pellagra.
1938: Vitamin B_6 was isolated independently by five different laboratories.
1938: The chemical structure of vitamin E was determined.
1938: Folic acid was discovered.
1939: Vitamin B_6 was synthesized.
1939: Snell and Strong introduced the microbiological method for determining the vitamin content of foods, replacing the crude and costly animal diet technique.
1940: Vitamin K was isolated and chemically identified.
1942: Snell demonstrated the existence of two other forms of vitamin B_6.
1946: The nature of folic acid was established.
1948: Vitamin B_{12} was isolated.
1950: The human ailment caused by lack of vitamin B_6 was established.
1956: The chemical structure of vitamin B_{12}, the most complicated vitamin structure known to date, was determined.

The first vitamin was isolated in 1926 with the discovery of vitamin B_1, the key to the control of beriberi, after a 26-year search. The second vitamin to be isolated, vitamin C, required 20 years of

EXHIBIT 27. THE PACE OF VITAMIN RESEARCH

Vitamin compound	Year search began	Number of years to isolate
B_1	1897	29
C	1912	20
A	1913	20
D	1918	12
E	1922	14
Niacin	1925	12
B_{12}	1927	21
K	1934	6
B_6	1936	2

research. From this point, the pace of research and development in the vitamin field began to accelerate rather rapidly (see exhibit 27.).

This acceleration can be attributed to two factors—the refinement of research techniques and the commitment of more time and funds to the task of isolating vitamins as their importance to health became increasingly evident. However, the time required to isolate some vitamin compounds was also a function of their complexity, the reason that 21 years was required to isolate the most complex vitamin, B_{12}. After these vitamins were isolated, additional time was needed to determine their chemical structure and discover how to synthesize them before commercial production could be undertaken.

The first commercial production of vitamins began in about 1937, with the introduction of vitamin C, and was followed 2 years later by niacin. The commercial growth of vitamins has been less than spectacular for three reasons:

1. The development of new vitamin compounds has taken place over a long period of time.
2. Vitamin compounds are relatively inexpensive when produced in large quantities.
3. The total per capita consumption of vitamins is by necessity very low because daily requirements are small.

In combination, these factors place a very definite limitation on the potential size of the vitamin market, and, therefore, on its past and future rate of commercial growth.

Antibiotics

The role of bacteria in causing infection has been known to medical science since the time of Pasteur in the 1870's, but very little work was done on developing agents that would attack bacteria within the body until the last 25 years. Most of the earlier research was concerned with antiseptic agents. Penicillin, the first antibiotic, was accidentally discovered by Fleming in 1929, but the publication of his results did not arouse interest for another 10 years (see exhibit 28). This lack of interest is particularly difficult to explain since Fleming demonstrated that penicillin was not toxic to human cells, whereas the antiseptics then in common use were even more toxic to human cells than bacteria.

EXHIBIT 28. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF ANTIBIOTICS

Incubation Period:

1929: Sir Alexander Fleming announced the accidental discovery of penicillin and its strong antibacterial action.
1939: A group of investigators at Oxford undertook a study of penicillin.

Commercial Development:

1940: The Oxford group, headed by Sir Howard Florey, succeeded in concentrating penicillin and demonstrated its remarkable curative properties.

Commercial Growth:

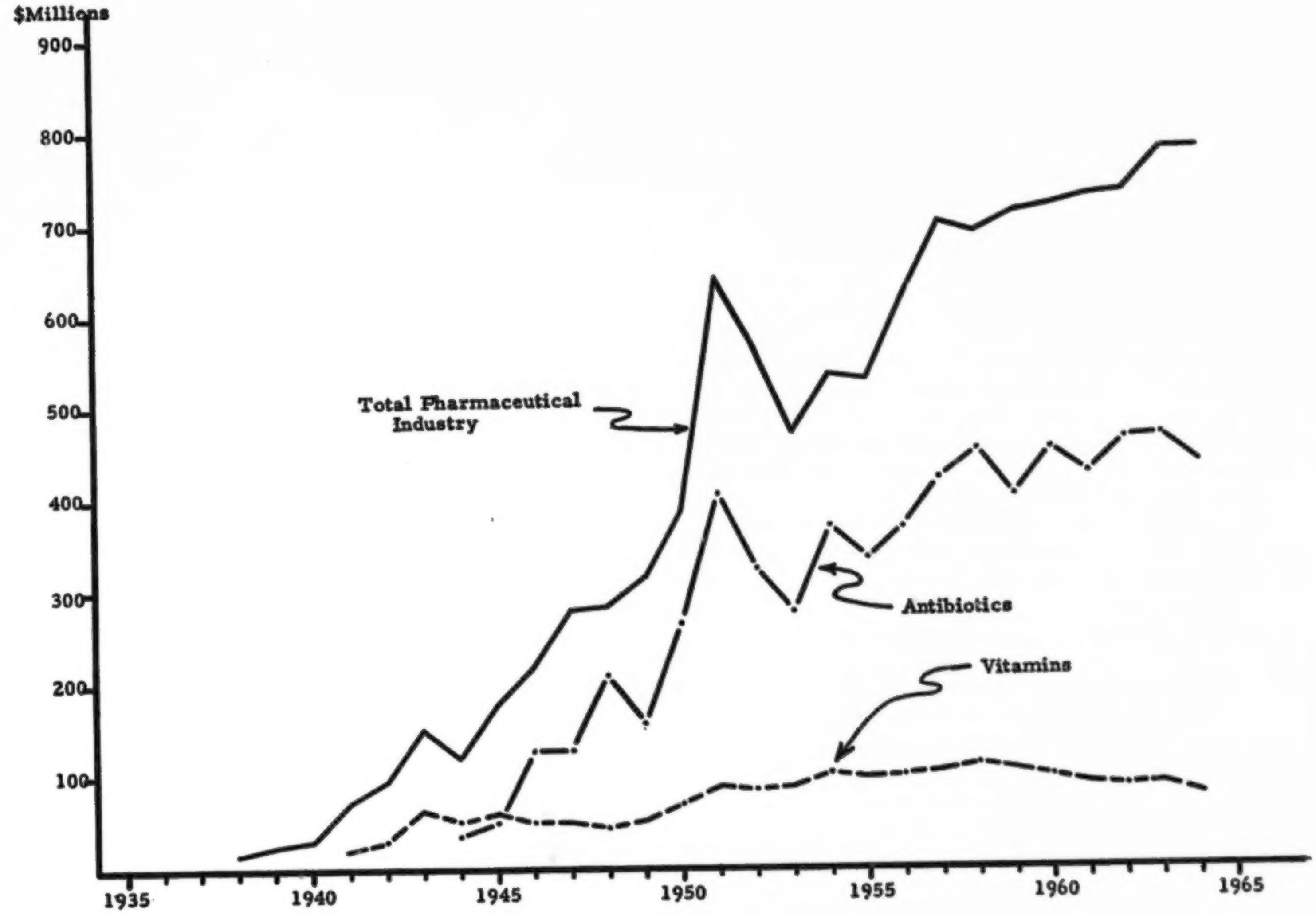
1941: After developing methods of production and extraction, Florey induced U.S. authorities to begin production of penicillin.
1944: Production of penicillin was still regarded as experimental, with nearly the entire output destined for the Armed Forces.
1944: Streptomycin was first identified.
1945: Penicillin began to reach civilian markets.
1957: Chloramphenicol, the first of the broad spectrum antibiotics, was identified and tested.
1948: Chlortetracycline (aureomycin) was discovered and tested.
1950: Oxytetracycline (terramycin) was discovered.
1950: Chloramphenicol was chemically synthesized.
1953: Tetracycline (achromycin) became available, largely replacing aureomycin and terramycin in medical practice because it produced fewer side reactions.

Initial commercial development work on penicillin was begun at Oxford in 1939, and within 2 years it was in production. Much of the impetus to its commercial development and growth was provided by wartime requirements, and during World War II the Government purchased the entire penicillin output of the pharmaceutical industry.

Penicillin proved so effective as an antibiotic that it spurred considerable research in this field during and after the war. As a result, more than 500 antibiotic agents have been investigated in depth, but only about 10 percent of these compounds have proved suitable for clinical use, and three—penicillin, dihydrostreptomycin, and tetracycline—account for the major portion of industry output. Of these, tetracycline has displayed the most dramatic growth, reaching an output level of $150 million within the first 4 years of its introduction.

The commercial growth of antibiotics has been much faster than vitamins, partially because its commercial development and growth were largely financed by the Federal Government, but more importantly because antibiotics are considerably more costly than vitamins. For example, the average price per pound for antibiotics was $301 in 1950 and $67 in 1964—approximately 10 times the per pound cost of vitamins. However, antibiotics, like vitamins, appear to have a ceiling on their use (there being just so much disease in this country)

EXHIBIT 29. THE ECONOMIC GROWTH OF TECHNOLOGICAL INNOVATIONS IN THE PHARMACEUTICAL FIELD



that limits the size of the market for these pharmaceuticals.

Conclusions

A comparison of the rate of commercial growth for both vitamins and antibiotics, as well as the growth of the entire pharmaceutical industry, is shown in exhibits 29 and 30. As suggested above, antibiotics have had a considerably faster rate of commercial growth than vitamins, principally because the size of the total antibiotics market has been considerably larger. Both these innovations reached a level of output equal to 0.02 percent of GNP in 5 years, but antibiotics continued this rapid growth, reaching a level of 0.10 percent of GNP in 10 years. The output of vitamins has yet to reach a level equal to 0.05 percent of GNP and probably never will. This comparison illustrates the importance of the total market in determining the economic impact of an innovation.

EXHIBIT 30. COMPARATIVE RATES OF COMMERCIAL GROWTH FOR ANTIBIOTICS AND VITAMINS

Criteria for evaluation	Lapsed time from commercial introduction (years)	
	Antibiotics	Vitamins
Date of commercial introduction	1940	1937
Absolute economic criteria in output: [1]		
$50,000,000	4	5
$100,000,000	6	6
$250,000,000	10	>28
Relative economic criteria in percent of GNP:		
0.02	5	5
0.05	5	>28
0.10	10	------------
0.15	>24	------------

[1] Adjusted to the 1957–59 index of wholesale prices.

7. Major Technological Innovations in the Transportation Field

The automobile and the airplane are particularly fitting subjects for this investigation of technological innovations because perhaps in no other area have advances in technology been more dramatic during the last 60 to 70 years than in the field of transportation. The development of the automobile and other motor vehicles (trucks, tractors, motorcycles, etc.) provided a personal mode of transportation with unparalleled mobility and speed, and at the same time brough many far-reaching social and economic changes which have created major problems in our society. For example, the rapid growth of the suburbs with the subsequent decline in urban populations and air pollution by exhaust gases are both directly and indirectly associated with the increasingly important role the automobile has come to play in our lives.

The impact of the automobile on this country's economy is undeniable. Automobile manufacture accounts for an important portion of the output of the steel and flat glass industries, and it is a significant consumer of plastics, aluminum, fabrics, and other materials. Manufacturers of motor vehicles and parts employ over 600,000 people, and an additional 2,400,000 are employed in areas directly related to the industry; for example, gasoline and service stations and car dealers. Added to this total are the many thousands of employees in industries supplying the auto industry and its component suppliers with basic raw materials. Further, the petroleum industry owes its growth and most of its present size directly to the motor vehicle industry. By virtue of its size (in 1964, industry output was $19.1 billion) the motor vehicle industry has become one of the keystones in our national economy.

In a similar manner, the development of the airplane as a means of public transportation is also producing significant changes in our economy. By increasing the speed by which individuals and freight can be transported by a factor of 10 during the last 40 to 50 years, the airplane has contributed greatly to the elimination of traditional regional and national boundaries and has helped foster the emergence of a truly national economy. With the continuing development of larger capacity high speed aircraft, another major new factor is being introduced into the transportation economy of this country.

The aircraft industry has also become an important part of our industrial economy; although not as great as that of the motor vehicle industry, it is still substantial. The industry's output, excluding military aircraft production, currently exceeds $1 billion, and commercial airline revenues are in excess of $3 billion. In terms of employment, there are over 400,000 workers in the industry, excluding those engaged in missile and space work, with an additional 200,000 employed in the commercial airlines.

Motor Vehicles

The development of the automobile occurred with the industrial revolution underway and at the end of a century deeply involved in the development and exploitation of any and all sources of power—steam, hot air, ammonia, and later, gas, oil, and gasoline (see exhibit 31). Power sources were being used in stationary as well as mobile applications, but the initial impetus was furnished by continuing experimentation with various mobile power sources, particularly the steam engine and the resultant steam powered vehicles. Concepts were evolved and mechanisms invented for the steam-driven vehicle which were employed later in the design of internal combustion engines and the automobile. By 1850, steam engine design for mobile application was at a technical plateau, and interest and activity were being redirected toward the development of smaller, more efficient and safer engines.

Although the automobile is often looked upon as a "tinkerer's product," the key to its development actually lies in two scientific discoveries—the definition of the laws of thermodynamics, which permitted a more specific approach to engine design, and the development of processes to convert coal to gas. The latter, plus the exploitation of petroleum deposits in the United States for illuminating gas, provided a high-energy readily available alternative to steam. Largely because of these events, a commercially successful gas engine was developed by 1860, followed in 1886 by a four-cylinder internal combustion engine.

Considering the interest in the internal combustion engine, the incubation period for the automobile was quite long—17 years. Two technical deterrents were largely responsible for this delay. The first was that internal combustion engines, initially designed for stationary powerplant applications, were consequently too cumbersome and

Exhibit 31. Chronology of the Discovery and Development of the Automobile

Basic Research and Investigation:

1680: The first explosion engine (using gunpowder) with a piston and cylinder was developed.
1690: The first piston and cylinder steam engine was invented.
1769: The high-pressure steam engine was developed by Watt using principles similar to those found in the modern engine.
1770: The first steam powered vehicle was developed by Cugnat to pull artillery.
1821: The steam powered vehicle was introduced as a commercial product.
1833: Differential gearing was developed.
1844: Goodyear patented the vulcanized rubber tire.
1845: Joule formulated a mathematical statement of the first law of thermodynamics relating heat and mechanical energy.
1851: A compressed gas engine ignited by a jump spark was patented.
1860: Gas engine with an electric spark ignition three times more efficient than steam engines was developed by Lenois.
1866: Otto and Langen perfected a successful two-cycle and four-cycle gas engine.

Incubation Period:

1872: A two-cylinder engine using fuel oil was patented by Brayton in the United States.
1880: A gasoline engine was invented in England by Lawson.
1883: Daimler developed and manufactured a high-speed, self-ignition, gasoline-operated engine.
1887: First car powered by the Daimler engine was manufactured.
1889: The pneumatic tire was patented by Dunlop (Ireland).
1890: Olds Gasoline Engine Works was organized.

Commercial Development:

1892: The automobile chassis was designed by Levassor (France).
1893: Pontiac Buggy Co. was incorporated.

Commercial Growth:

1895: The first United States designed and manufactured automobile was marketed.
1897: Olds Motor Vehicle Co. was organized.
1899: The first factory for the exclusive production of automobiles was built.
1902: Cadillac Motor Co. was organized.
1903: Buick Motor Co. was organized.
1903: Ford Motor Co. was established.

heavy to be used as mobile powerplants. The second lay in the very complicated flame ignition system used on internal combustion engines which were unable to achieve the high rate of rotation required for motor vehicle applications. These problems were resolved in 1883 when Daimler in Germany developed and patented an internal combustion engine with the desired characteristics.

The subsequent period required to develop a satisfactory commercial motor vehicle engine was very short. In France, less than 4 years elapsed between the development and application of Daimler's high-powered internal combustion engine to an automobile for commercial production. By 1890, France's automobile industry was well established and in production. The establishment of the automobile industry in this country lagged behind France's by about 10 years, since much of the experimentation in motor vehicles was being undertaken by individuals and small firms with very little knowledge of the progress being made in Europe. Surprisingly, initial commercial interest in the automobile was shown by bicycle manufacturers, at that time a growing industry, who were among the first to produce electric and gasoline powered cars.

With the commercial introduction of the automobile in 1895 by bicycle manufacturers, carriage and wagon manufacturers also logically entered the business. By the turn of the century, a number of firms were actively engaged in manufacturing automobiles, and a variety of steam, electric, and gasoline powered cars were being produced. As the industry grew, a split between the high-priced and low-priced cars developed which climaxed with the introduction in 1908 of Ford's Model T and the formation of the General Motors Corp. The next 5 years were a period of considerable turmoil in the automobile industry. As mass production techniques and moving assemblyline were introduced the result was a reduction in the cost of motor vehicle manufacturing to where this innovation began to have widespread consumer appeal.

The automobile presents an interesting study in the adaptation of technology to meet consumer demands. The key technological innovation was not the automobile itself, but the lightweight internal combustion engine. When incorporated into a carriage, it became a new mode of transportation. With the introduction of mass production techniques, the cost of motor vehicles declined to where widespread consumer ownership was possible. In addition, a crude but usable road system existed because of horse drawn carriage transportation requirements. Furthermore, a primitive fuel distribution network already existed because of the widespread use of kerosene for home heating and lighting. With all these supporting factors already in existence, the motor vehicle industry was able to grow rapidly, reaching a level of $1 billion by 1916 and $3 billion by 1926. It has continued this growth in modern times.

Air Transportation

During the 1800's, considerable interest existed in airship development, primarily in such lighter-than-air types as balloons, gliders, and even kites (see exhibit 32). Although patents were granted for steam engine propelled airships, and several of these did get off the ground, the heavy weight and low power output of the steam engine precluded any successful development of a heavier-than-air craft during this period. At the same time, the theoretical basis for the science of aerodynamics was being developed through these efforts. Scientific and experimental effort was also being devoted to the glider and airplane models and to determining aerodynamic design and control requirements.

The successful development of the lightweight, high-power internal combustion engine in 1885 opened the door to the possibility of finally achieving flight in a heavier-than-air craft. After many failures, the first sustained flight was achieved in 1903 by the Wright brothers.

During the next 5 to 6 years substantial but gradual improvements were made in the capabilities of the airplane. The Wright brothers extended their time of flight from the original 12 seconds to 30 minutes (21 miles) in 1905, and in 1908 to 2 hours and 20 minutes (90 miles). By 1909, airplanes built by others achieved a flight duration record of more than 3 hours, a speed record of 50 miles per hour, and an altitude record of 500 feet. Considerable activity was also taking place in Europe with numerous flights being made and shortrun, passenger-carrying operations established. Developments were then still mainly in the hands of individual designers, inventors, and experimenters, but the airplane had reached a point where commercial development could begin.

Exhibit 32. The Chronology of the Discovery and Development of the Airplane

Research and Development:

1842: A patent was issued for a steam driven airplane.

1845: Stokes developed a series of equations describing the motion of viscous fluids.

1848: The first successful flying model airplane was developed.

1867: The first biplane was designed by Wenham (England).

1890–1900: Detailed scientific gliding experiments by Chanute and others helped establish the principles of aerodynamic control.

1896: The first motor driven airplane achieved sustained flight.

1901: The Wright brothers conduct wind tunnel tests to determine proper aircraft design requirements.

1902: The Wrights continued their experiments with gliders.

1902: The role of the airfoil in producing lift was explained.

1903: The Wright brothers demonstrated the technical feasibility of the airplane by achieving a 12-second sustained flight using a 12-horsepower internal combustion engine.

Incubation Period:

1905: The Wrights extend flight duration to 33 minutes covering 21 miles.

1908: The capacity for sustained flight was further extended to 2 hours 20 minutes.

1908: A practical monoplane design was introduced.

Commercial Development:

1909: A flight duration record of 3 hours 4 minutes and 56 seconds, a speed record of 50 miles per hour, and an altitude record of 500 feet all were established.

1909: The U.S. Army placed the first order for the manufacture of aircraft with the Wright brothers.

Commercial Growth:

1917: The Wright-Martin Co. and other plane manufacturers were established.

1918: The first regular airmail service in United States was inaugurated.

1919: The first transatlantic flight by Lindberg was successful.

1919: Commercial airlines began limited activities.

1926: The Post Office Department turned airmail routes over to private industry.

1927: Lindbergh's New York to Paris flight aroused the public.

1928: United Aircraft & Transport Corp. were formed.

1928: The Aviation Corp. of Delaware (American) was formed.

1930: The jet engine was invented by Whittle (England).

1930: Transcontinental and Western Air (TWA) began operations.

1939: The buildup of military aircraft prior to World War II was started.

The first order from the U.S. Army for an airplane spurred commercial development. During World War I, design and development activities were accelerated, the scientific principles of aerodynamics were more rigorously employed, metal was substituted for wooden parts, engines were developed specifically for airplanes, and frame design was improved. The continued interest of many individuals and particularly the airplane's military potential resulted in the aircraft industry's coming of age commercially in 1917.

The Post Office Department's interest and financing of airmail service after the war greatly assisted the initial stage of the aircraft industry's commercial growth, which provided an important impetus to the new industry for almost a decade until the service was turned over to private industry in 1926. The experience gained through the airmail service and the air routes that were established became the base for the emerging commercial airline industry. The future of commercial aviation was also aided considerably by Lindbergh's New York to Paris flight, which altered the general public's apathetic attitude toward airplanes and doubts about their safety.

Large commercial airline holding companies began to appear in 1928. During the next 15 years, technological progress continued with the development of new commercial aircraft and engines. Again war, this time World War II, brought military demands for aircraft which resulted in a substantial acceleration in aircraft technology. First the turboprop was produced, and later the jet engine. The overall freight and passenger capabilities of military, and eventually civilian aircraft were also generally improved.

Very important to the commercial growth of aircraft transportation is the Federal Government's role in the creation of the industry. World War I purchases of military aircraft gave the industry a substantial commercial impetus, increasing sales from almost nothing to above the $50-million level in a very short time. Unfortunately, sales dropped almost as quickly after the war and with no sustained military buying, there was practically no growth in either the aircraft or commercial airline industries for the next 10 years.

The second impetus to the industry's commercial growth was provided by the Post Office Department. At that time, the airplane was still somewhat of a curiosity, commercial airline companies were small and still in the "puddlehopping" stage, military purchases had fallen off completely, and aircraft companies had very few customers. The inauguration and continuation of airmail service provided sufficient income for fledgling companies to maintain their interest until the time that aircraft and airline companies would achieve the necessary public support to sustain themselves. Even to this day, airmail revenues are still an important aspect of the airline industry's revenue.

The more recent Federal Government contribution to the technological progress of the aircraft and airline industries is well known. Research and development efforts during World War II and the Korean war resulted in the jet engine and jet transport which was adopted almost directly by the commercial airlines. More recently the Federal Government has undertaken the development of a very large cargo transport which is expected to have direct applications in commercial air transportation, and it is financing most of the development work on a supersonic transport for passenger use. Thus, it is apparent that the Federal Government is largely responsible for the development and growth of the air transportation industry as we know it today.

Conclusions

The commercial growth of the motor vehicle industry is shown in exhibit 33, which provides a dramatic illustration of the contribution of this innovation to the overall growth of our economy during the last 20 to 25 years. Prior to World War II, the motor vehicle industry's growth closely reflected the condition of the country's economy, increasing substantially during the prosperity of the 1920's, declining rapidly during the early 1930's, and recovering again just before the war started. However, the commercial growth of the motor vehicle industry after the war ended saw the industry's output increase from $1.2 billion in 1945 to $10.2 billion by 1955, and it has continued to increase until, in 1964, it was slightly less than $18 billion.

The commercial growth of the air transportation industry is shown in exhibit 34, which includes commercial airline revenues along with output from aircraft manufacturing. This pre-

EXHIBIT 33. ECONOMIC GROWTH OF THE MOTOR VEHICLE INDUSTRY

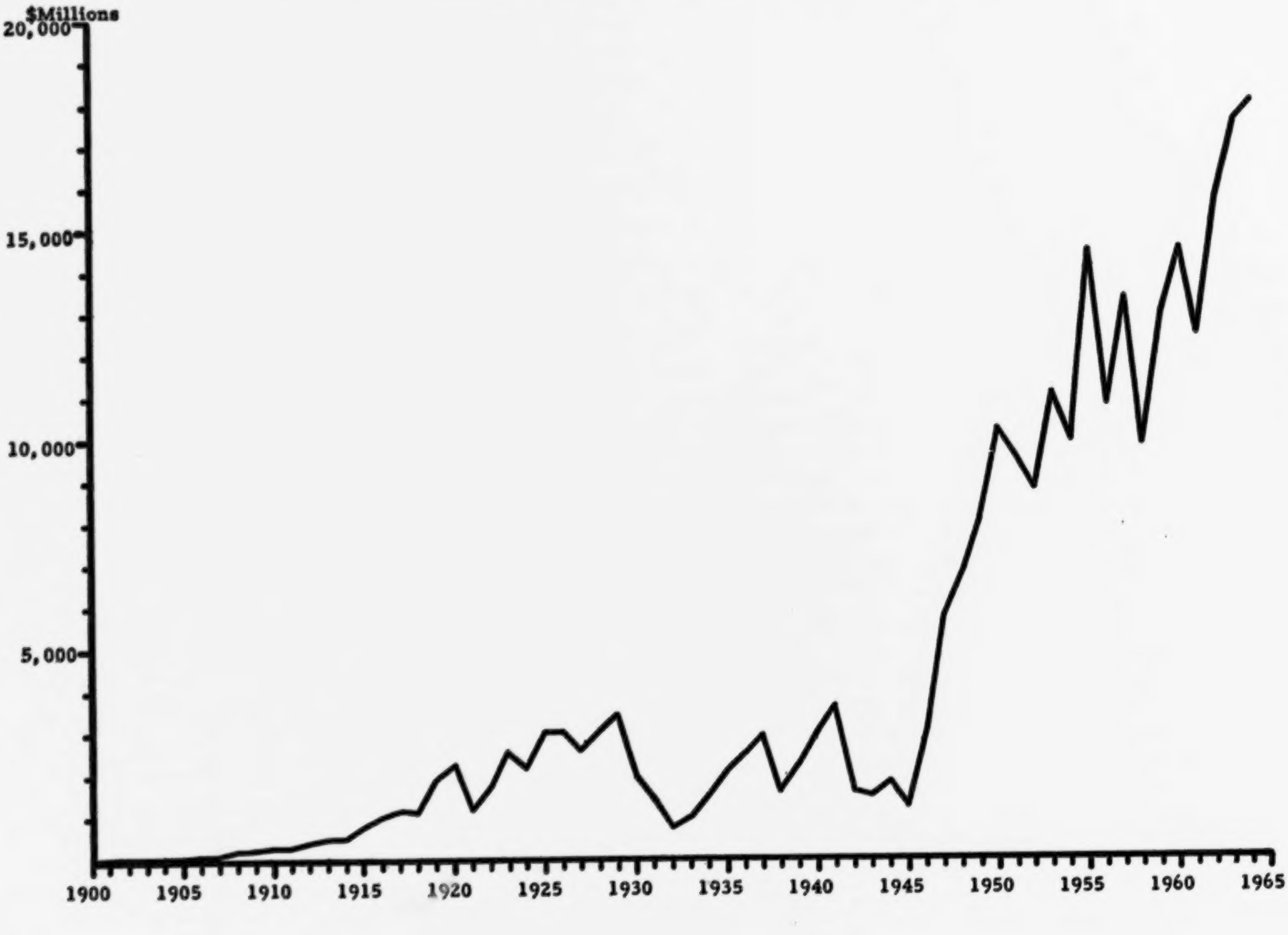
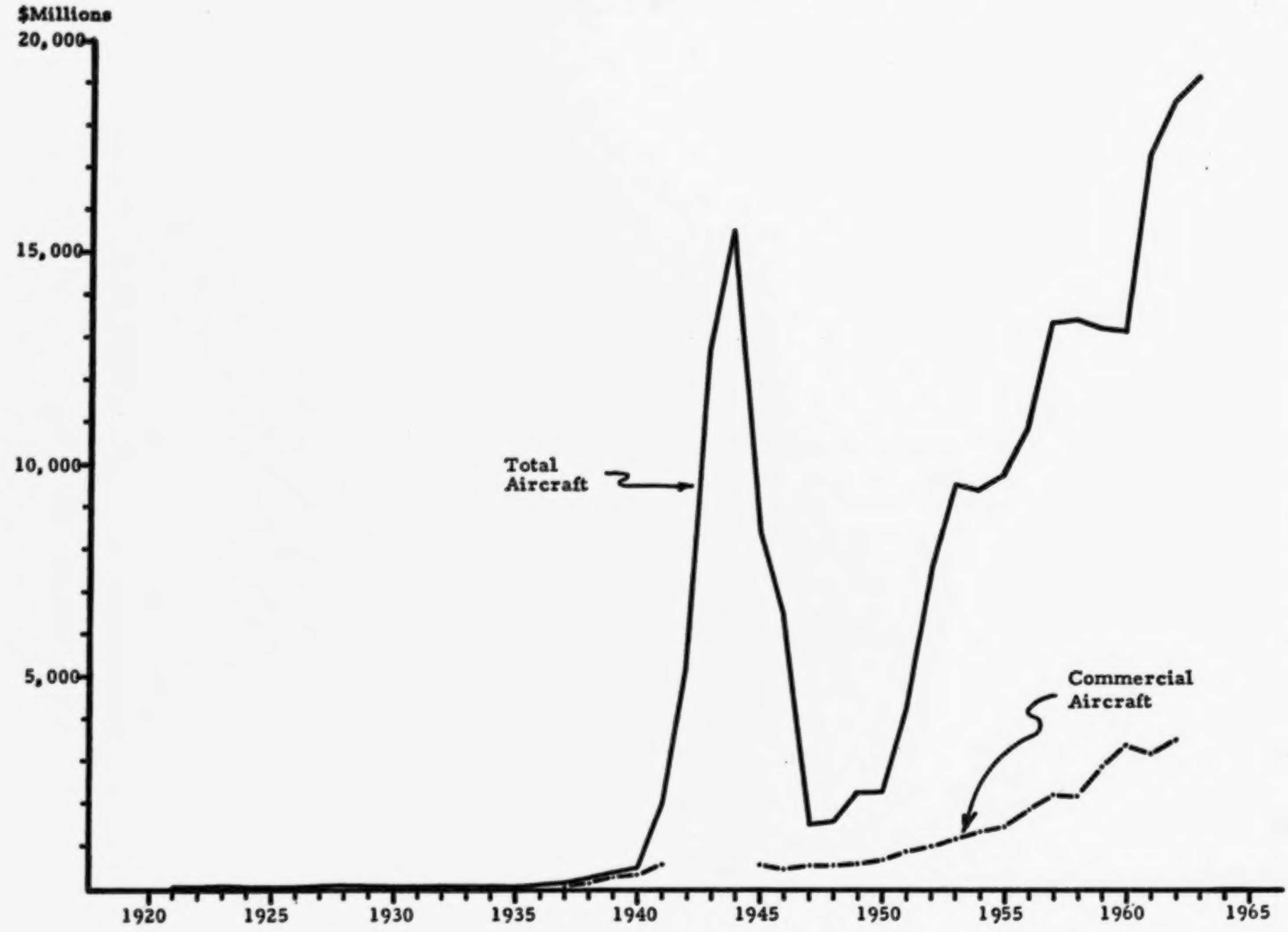


EXHIBIT 34. ECONOMIC GROWTH OF THE AIRCRAFT INDUSTRY



sents an entirely different picture, with the prosperity and growth of the industry closely tied to military rather than consumer requirements. The extent of the Federal Government's participation in this industry is also vividly demonstrated. The lower curve on the graph represents the combined total of commercial airline revenues and output of aircraft for private and commercial applications. The area between the two curves represents the Federal Government's purchases of aircraft for military use during World War II. The extent of these and of purchases during the Korean war is predictable, but it is surprising to see that military aircraft purchases currently account for slightly more than 80 percent of the air transportation industry's total output.

Exhibit 35 provides a direct comparison between the relative and absolute rates of economic growth for both innovations. The relative rate of economic growth for motor vehicles exhibited the rapid but steady increase discussed above. Twenty

EXHIBIT 35. COMPARATIVE RATES OF COMMERCIAL GROWTH FOR MOTOR VEHICLES AND AIR TRANSPORTATION

Criteria for evaluation	Lapsed time from commercial introduction (years)	
	Motor vehicles	Air transportation
Date of commercial introduction	1895	1917
Relative economic criteria in percent of GNP:		
0.02	5	8
0.05	7	17
0.10	9	25
0.15	10	26
0.20	11	26+
0.25	13	28
0.50	15	29
0.75	17	30
1.00	20	30+
Absolute economic criteria in $million output: [1]		
50	8	10
100	10	11
250	12	20
500	15	21
750	16	22
1,000	17	23
1,500	20	23+
2,000	28	24

[1] Adjusted to the 1957-59 index of wholesale prices.

years after commercial introduction, the motor vehicle industry had reached a level of output equal to 1 percent of GNP—a more rapid overall rate of economic growth than any other studied in this investigation, and approached only by television. At the present time, the output of the motor vehicle industry is equal to approximately 2.9 percent of GNP.

This chart also confirms that the aircraft transportation industry had a relative slow rate of commercial growth during its early years. Eight years were required to attain an output equal to 0.02 percent of GNP, and an additional 9 years to reach the next level, 0.05 percent of GNP. The rapid rate of economic growth for this industry was, then, primarily a result of the artificial stimulus provided by the military requirements of World War II.

8. Other Recent Major Technological Innovations

In addition to innovations that fall into "families," three others with no common denominator were selected for investigation because they are expected to have an important influence on our industrial economy during the next 5 to 10 years. These innovations—electronic computers, nuclear power generation, and numerical control—are rather recent compared to many of the others reviewed in this study. Of them, only electronic computers have attained a level of commercial growth sufficiently large to be valuable in assessing the rate of diffusion of technology; the other two have only recently attained the lower levels of economic growth. Nevertheless, all three innovations provide an opportunity for an insight into recent changes in the rate of development of technology and, particularly, the extent to which Federal Government sponsorship of research and development influences this rate of development.

Electronic Computers

The electronic computer must rank as one of the outstanding technological developments of the last 25 years. While mechanical calculating and tabulating machines have been in existence since the early 1900's, the electronic computer introduced a new concept in information recording and analysis by permitting information to be processed many times faster and more accurately than any previous methods. Although simple in concept, this ability has far-reaching effects, since the effective control of business, scientific, and Government activities involves the accumulation, transmission, processing, and analyzing of information. Furthermore, computers permit information processing which hitherto has been impractical, if not impossible, with electromechanical calculating equipment.

The computer's impact on industry, government and science has already been substantial in the relatively short time since its development; it is expected to be even greater in the future. The computer was originally used for scientific and mathematical calculations and routine business applications. However, increased operating speeds, larger memories, and, particularly, greater knowledge and experience in applying them effectively to complex problems are enabling computers to be used in many new applications—process and equipment control, information storage and retrieval, engineering design, language translation, and communications.

The electronic computer is interesting as a technological innovation in that the scope of computer applications was rapidly and continually broadened by technological developments in other fields, particularly electronic circuitry. In addition, computer technology was generally available to almost any interested company, but it was most successfully exploited by one, International Business Machines Corp. The Federal Government has played a continuing role in the computer industry, both as a major customer for computers and, more importantly, as the primary source of research and development funds for advanced computer systems for both military and commercial applications.

Fundamental research in the electronic computer field has proceeded in two separate steps. The first was the successful development and commercial exploitation of unit-record machines (tabulating card equipment) that tabulate and compute; and second, the successful design of an electronic computer with internal programed control. The evolutionary aspects of electronic computer development date back to 1885 with the development of the first mechanical computing machine to add and count U.S. census data (see exhibit 36). Further development and refinement of electromechanical equipment such as keypunch machines, printers, card readers, and punches (which are still required as input and output machines for electronic computers) took place over the next 50 years. Between 1929 to 1944, research efforts were directed at developing mechanical and electrical relay computers, culminating in the automatic sequence controlled calculator, the first large scale electromechanical computer.

At this point, technological developments began to move quite rapidly as a result of wartime developments in the electronics area. For example, vacuum tubes increased computing speeds by a factor of 1,000 over the electromechanical computer. The introducing in 1948 of two new concepts—the internally stored program and the "computer memory"—transformed the computer from a high-speed adding machine to its present status of "electronic brain." Further developments in magnetic recording technology and the development of transistors and other semiconductor devices permitted even larger memory storage and faster processing rates. As a result the computer became

Exhibit 36. Chronology of the Discovery and Development of Electronic Computers

Basic Research and Investigation:

1822–32: Babbage proposed the design of a "difference engine to construct and print mathematical tables and an analytical engine for scientific calculation."

1885: Hollerith developed the punched-card counting machine for tabulating the 1890 census.

1890: Relay apparatus was developed for controlling complex electrical switching.

1911: The development and marketing of mechanical tabulating card equipment was initiated.

1923: The electric key punch was introduced.

1925: The horizontal card-sorting machine was introduced.

1928: Standards for punched cards were established.

Incubation Period:

1929–44: A number of special computing machines, including the first large scale electromechanical computer, the automatic sequence controlled calculator (with a capacity of three additions per second), were developed.

Commercial Development:

1946: The first vacuum tube electronic computer, ENIAC (with a capability of 5,000 additions per second), was put into operation at Aberdeen Proving Ground.

1948: The first electronic stored program computer with large electromechanical relay memory (SSCE) was constructed.

1948: The small electronic 604 computer was introduced by IBM.

1949: The Edsac computer employing a mercury delay-line memory was developed.

Commercial Growth:

1951: The UNIVAC I computer became the first electronic computer introduced for commercial applications.

1953: The first solid state computer was delivered.

1956: The magnetic core storage computer was announced.

1959: The first thin-film integrated circuits for computer memory were developed.

1965: Delivery of the first integrated circuit computers for commercial applications began.

not only technically but economically feasible for a wide range of scientific and business applications.

Technological advances have continued to play an important role in the development of electronic computers of varying sizes and types. Memory sizes have continued to increase at lower costs, processing speeds have increased, and "software" programing has become more sophisticated. In 1965, the third generation of electronic computers using microelectronic circuits was introduced. Because the new machines have even greater technical and economic capabilities, they are expected to further enlarge the scope of electronic computers further to encompass "shared time" and "on-line" data processing concepts.

Nuclear Power Generation

Nuclear power generation has yet to make its mark on our economy, with second generation nuclear power electrical plants only now reaching the design stage. Compared to the total output of the electric utility industry, the contribution of nuclear energy to power generation is barely measurable. However, the growing acceptance of nuclear power by the major utilities is evident in the announced expansion and now installation of nuclear power generation plants, which indicate that the major technological and safety problems have been resolved. With the trend to larger central generating stations, nuclear power is expected to improve its cost relationship in comparison to coal-powered generating plants, with the result that nuclear power generation plants will play an increasing role in the country's total electric generating capacity.

The history of the development of nuclear energy and its application for electric power generation is fairly well defined in a series of fundamental scientific discoveries and developments (see exhibit 37). Over the last hundred years, the mysteries of the atom have attracted many scientists, a number of whom have won the Nobel prize for their work in such areas as atomic theory, fundamental particles, radiation and energy, atomic structure, natural and artificial radioactivity, nuclear transmutation, isotopes, and isotope separation. Fundamental research was done over a considerable period of time with no end objective other than the resolution of the atom's mysteries at the most fundamental scientific level. This basic research culminated with the practical demonstration of nuclear fission in 1942, with the first controlled chain reaction at the University of Chicago. Although crude in comparison with modern-day nuclear power reactors, it demonstrated the technical feasibility of obtaining large quantities of heat energy from the atom. This practical demonstration of nuclear energy resulted from the Federal Government's interest in the military potential of an uncontrolled release of nuclear energy. Without this incentive, the basic research would have probably extended into many more years.

A large amount of technical effort, research facilities, and financial investment was required to resolve the technological problems of power reactor design and the associated problems of materials development, fabrication techniques, chemical processing, and control and instrumentation. During World War II, the Federal Government expended major funds and efforts on the design and construction of power reactors for military use, particularly naval applications, as well as a series of experimental reactors to study the many problems associated with nuclear power reactor design. These experiences accelerated the eventual introduction of the commercial power reactors for electrical generation.

A particularly difficult technical problem arose from the large number of designs available for commercial power reactors. This was eventually resolved in favor of the watercooled, thermal, nonbreeder, and heterogeneous reactors, principally

Exhibit 37. Chronology of the Discovery and Development of Nuclear Power Generation

Basic Research and Investigation:

1896: Henri Becquerel observed the emission of spontaneous radiation for uranium.
1898: Pierre and Marie Curie conducted further investigations of radioactive elements.
1900: Max Planck developed a quantum theory.
1905: Albert Einstein postulated the theory of relativity.
1911: Ernest Rutherford defined the concept of the atomic nucleus.
1914: Experiments with the conversion of matter to energy demonstrated the validity of Einstein's equations.
1930–32: The neutron was discovered and confirmed.
1932: The "cascade" gaseous diffusion principle for separation of isotopes was discovered.
1936: Niels Bohr formulated the theory of neutron capture and nuclear disintegration.
1938: Atomic disintegration of uranium (fission) was discovered by Hahn and Strassman.
1942: The first practical demonstration of controlled nuclear chain reaction took place at the University of Chicago.

Incubation Period:

1943: The Oak Ridge reactor for producing plutonium was placed in operation.
1943: The reactors at Hanford for producing uranium were put in production.
1943: A gaseous diffusion plant to separate U^{235} from U^{238} was constructed.
1945: The first atomic bomb was exploded.
1946: The Atomic Energy Act of 1946 (the civilian control bill) was passed by Congress.
1948–56: Experimental nuclear reactors for naval applications were developed and tested.
1951: The industry participation program to encourage development of power reactors was established.
1951–53: Construction of the AEC's first series of experimental reactors was begun.

Commercial Development:

1954: A 60,000 kilowatt unit at Shippingport, Pa., jointly financed by Duquesne Light Co. of Pittsburgh and the Atomic Energy Commission, was announced.
1954: The Atomic Energy Act of 1954, with strong encouragement for private development of nuclear power generation, was passed by Congress.
1955: Commonwealth Edison, Consolidated Edison, and Yankee Electric announced plans to build full scale nuclear power generation plants.

Commercial Growth:

1960: Electrical power was first generated by the 210,000 kilowatt Dresden nuclear generating plant of Commonwealth Edison.
1960: The 185,000 kilowatt Yankee plant was placed in commercial operation.
1962: The 275,000 kilowatt Indian Point nuclear power plant owned by Consolidated Edison was placed in operation.
1963: A 495,000 kilowatt plant was announced by Connecticut-Yankee for completion in 1967.
1965: A 800,000 kilowatt Dresden-II plant due to be completed in 1969 was announced.
1965: A second plant (1,000,000 kilowatt-hours) by Consolidated Edison to be in operation by 1969 was announced.

because of the demonstrated success of the naval reactor program, the AEC's experimental reactor program, and the experiences of industrial companies. Commercial development of reactors for power generation started in 1954 with the announcement of a 60,000-kilowatt electric plant at Shippingport, Pa. It was followed by the passage of the Atomic Energy Act of 1954, which encouraged the participation of industry in the development of nuclear energy for electrical generation through programs jointly funded by the AEC and utility companies. In 1955, three utility companies announced plans to build full-scale nuclear power generating plants.

The continued growth of the nuclear power generation field has been fostered by further financial assistance from the AEC, active interest and participation by the electrical utilities, and manufacturers of nuclear equipment, and by the resulting solution of many technical problems. As a result, 11 nuclear power electrical generating plants with a total capacity of 1,042,000 kilowatts have been built to date, and produced 25,970 million kilowatt-hours of electricity by 1964. The future role of nuclear power generation is well defined. The 11 "first generation" nuclear plants placed in operation between 1957 and 1966 have a total electrical capacity of 1,250,000 kilowatts; the "second generation" plants now under construction or expected to be completed between 1967 and 1975 will have an estimated total electrical capacity of 14,180,000 kilowatts. At a capital cost of $200 per kilowatt, this is equivalent to an investment of almost $3 billion between 1967 and 1975. Of all projected new electrical generating plant capacity, it is estimated that 46 percent will consist of nuclear plants by 1980, compared to only 6 percent in 1965.

Numerical Control

Three basic types of manufacturing techniques are used throughout almost all of industry—mass production, continuous process, and job shop production. Two of these, mass production and continuous process manufacturing, are similar in that they are both concerned with high volume, low unit cost manufacturing of standard products on highly mechanized and automated machinery and production equipment. Mass production manufacturing is typically found in the automotive and appliance industries, whereas continuous process manufacturing is found in the steel, petroleum, aluminum, chemical, and cement industries. In all of these, production requirements justify the large capital investment for specially designed equipment. Job shop production is concerned with the manufacture of a large variety of items in small quantities on flexible, general-purpose production equipment. It is less widely known than the other two manufacturing processes, but it is an important element in our industrial economy. An estimated 75 percent of all production in the metalworking industries in this country is in quantities of 50 items or less, and this job shop type of manufacturing is found to some extent in most industries. It is important to this investigation because numerical control will have its greatest impact in this area.

Numerical control is probably the most significant new development in manufacturing technology since Henry Ford introduced the concept of the moving assembly line. It brings to job shop production many of the manufacturing economies now available only with highly automated production systems. Although numerical control has applications in many areas of manufacturing, for example, assembling and wiring electronic circuit boards and producing engineering drawings and flame-cutting metal templates, its most significant application is in the control of metal-cutting machine tools. Numerical control provides instructions to these machine tools in the form of coded instructions punched on paper tape. These instructions control the operation of the machine, position the item to be machined, and select the proper cutting tools for each operation. They enable the machine tool itself to perform most of the functions that are done by the machine operator on conventional machine tools.

The concept of a flexible system for controlling the operation of production machinery has a far longer history than generally realized (see exhibit 38). The first patent on such a machine was issued in France in 1725 to Falcon, who developed a knitting machine controlled by a perforated card. Another French inventor, Jacquard, patented a knitting and weaving machine controlled by punched cards in 1804. In 1916, an American, Scheyer, patented a continuous-path cloth cutting machine for the garment industry that was controlled by perforations in a roll of paper similar to that used on a player piano. Twenty-four years later, this concept of controlling machines with "programed" instructions was applied to machine tools. All these developments incorporated the basic principles of numerical control, but since the control systems were primarily mechanical in nature, they lacked the versatility and reliability needed for widespread commercial application.

The commercial development of numerical control in its present form started with a proposal to the U.S. Air Force by John Parsons Corp. to study the feasibility of developing a numerically controlled jigboring machine tool to produce inspection templates for helicopter blades. The initial study was undertaken in 1948 by the Parsons Corp. and later by Massachusetts Institute of Technology. While this investigation was under way, the Air Force made a comprehensive study of manufacturing requirements for its future aircraft. This study indicated that the changing structural characteristics of the new aircraft and their vastly higher cost, which limited the number of aircraft that could be purchased, prohibited the massive tooling programs that characterized aircraft reproduction during World War II. The answer, then, lay in highly flexible, versatile production machines, particularly machine tools, which could perform a variety of different functions and be quickly converted from one task to another. Since the Parsons-MIT research program held promise of providing the needed answer, its scope was enlarged.

EXHIBIT 38. CHRONOLOGY OF THE DISCOVERY AND DEVELOPMENT OF NUMERICALLY CONTROLLED MACHINE TOOLS

Basic Research and Investigation:

1725: A French inventor, Falcon, patented a knitting machine controlled by a perforated card.

1804: Another French inventor, Jacquard, patented a knitting and weaving machine controlled by a punched card.

1916: An American inventor, Scheyer, patented a continuous-path machine for cutting cloth in the garment industry that was controlled by perforations in a roll of paper similar to that used to operate a player piano.

Incubation Period:

1930: A patent was issued to Max Schenker for a method for controlling the operation of machine tools by punched cards.

1946: John Parsons proposed the development of a numerically controlled jig-boring machine to manufacture inspection templates for helicopter blades.

Commercial Development:

1948: The U.S. Air Force awarded a contract to the Parsons Corp. to investigate the feasibility of numerically controlled machine tools.

1949: MIT was issued a contract by the Parsons Corp. to develop a prototype model of a numerically controlled milling machine.

1951: MIT was awarded the prime contract by the U.S. Air Force to continue development of a numerically controlled milling machine.

1952: The first prototype of a numerically controlled machine tool, a modified vertical milling machine, was demonstrated at MIT.

1953: MIT made the results of its research and development work on numerically controlled machine tools available at no cost to all interested companies.

1954: A contract was awarded to the Giddings & Lewis Co. to develop a commercial numerical control system for machine tools.

Commercial Growth:

1955: The first commercial numerically controlled machine tools were exhibited at the National Machine Tool Show.

1955: The U.S. Air Force placed initial orders for numerically controlled machine tools.

1957: Numerically controlled machine tools were placed in operation at various Air Force contractor's plants throughout the country.

1960: Five percent of machine tools on display at the National Machine Tool Show were equipped with numerical control systems.

1962: The development of low-cost, point-to-point numerical control positioning systems expanded the application of numerical control in the machine tool field.

1963: The introduction of solid-state electronic controls with modular circuit construction increased the reliability of numerical control systems significantly.

1965: Most of the machine tool manufacturers exhibited numerical controlled equipment at the National Machine Tool Show.

The first successful demonstration of a numerically controlled machine tool was held at MIT in 1952, 4 years after the initial feasibility study was started. Based on these results, the Air Force contracted a machine tool company to manufacture numerically controlled machine tools for use in the production of military aircraft. The first commercial versions of these units were shown at the National Machine Tool Show in 1955, and since then, numerically controlled machine tools have become an important factor in the metalworking industries.

The key to the growing acceptance of numerical control for commercial applications was the introduction of solid-state control units, which provided a degree of reliability of operation that made numerical control feasible for most commercial machine tool applications. As a result, sales of numerically controlled machine tools have increased rapidly, from $48 million in 1961 to $84 million in 1963. In 1964, sales amounted to $106 million, 12 percent of total metal-cutting machine tool sales. In addition, numerical control is quickly finding applications in other areas of metalworking manufacturing—flame cutting, piercing holes, cutting sheets of steel to proper lengths, and welding—as well as in such other areas as writing of panel boards for computers, assembling electronic components, and production of engineering drawings.

Conclusions

Because these three innovations have been in commercial existence for a relatively short period of time, they provide a limited opportunity to measure the rate of commercial growth in our industrial economy. Unfortunately, only electronic computers have attained a level of economic growth (see exhibit 39) substantial enough to permit a comprehensive comparison with technological innovations with a longer history of economic growth. The time required for each of these innovations to reach the economic benchmarks used as a basis of comparison in this study are shown in exhibit 40. As this chart indicates, electronic computers have had a more rapid rate of absolute and relative economic growth than the other two innovations during the early stages of commercial application. In fact, electronic computers have had a faster overall relative rate of economic growth than any of the 20 innovations investigated in this study except radio and television broadcasting.

EXHIBIT 39. THE ECONOMIC GROWTH OF OTHER RECENT TECHNOLOGICAL INNOVATIONS

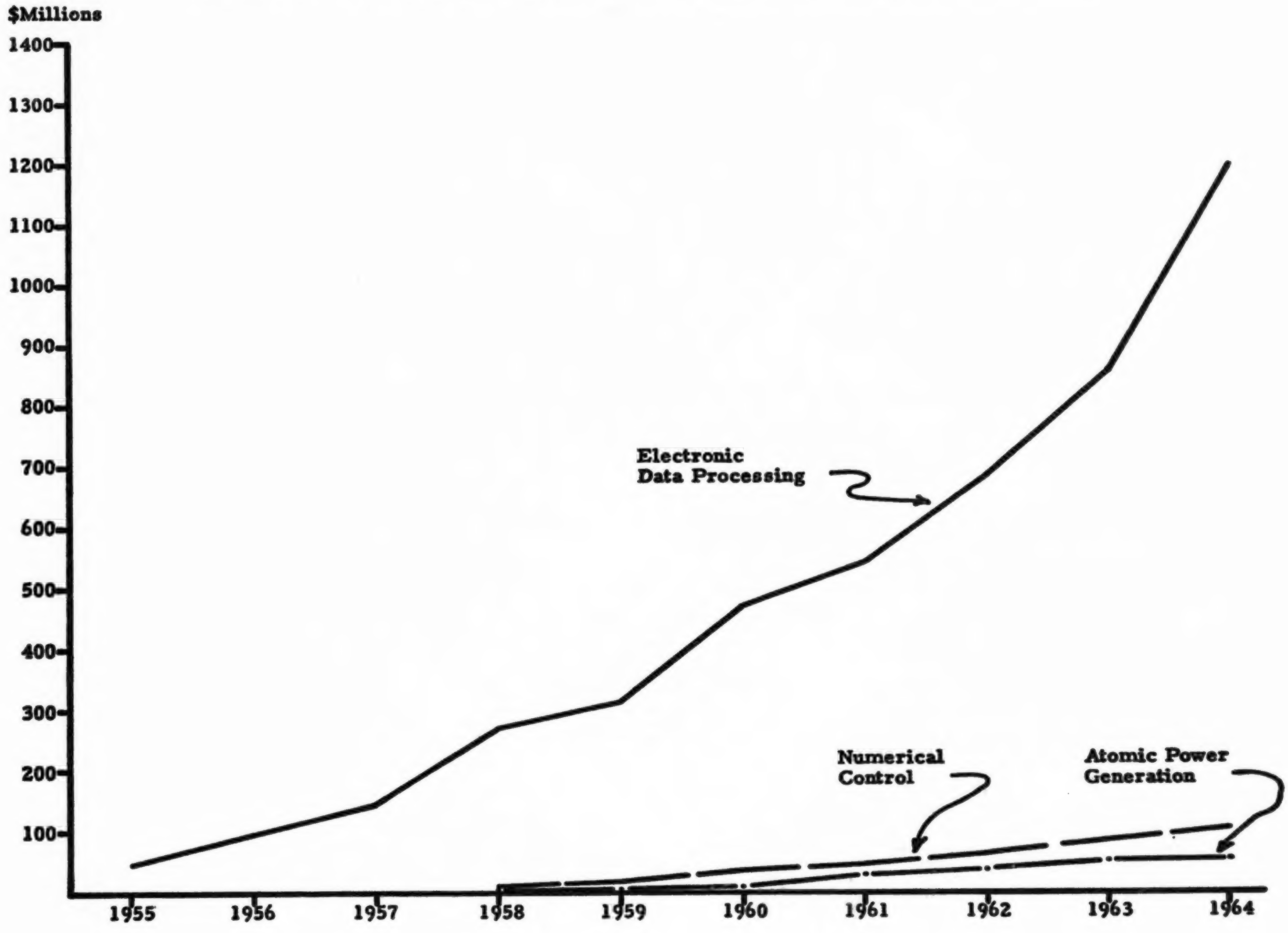


EXHIBIT 40. A COMPARISON OF THE RATE OF COMMERCIAL GROWTH FOR ELECTRONIC COMPUTERS, NUCLEAR POWER GENERATION, AND NUMERICAL CONTROL

Criteria for evaluation	Lapsed time (years)		
	Electronic computers	Numerical control	Nuclear power generation
Date of commercial introduction	1950	1955	1957
Relative economic criteria in percent of GNP:			
0.02	6	9	>7
0.5	8	>9	------
0.10	11	------	------
0.15	13	------	------
0.20	14	------	------
0.25	>14	------	------
Absolute economic criteria in $ million output:[1]			
50	5	6	6
100	6	10	>7
250	8	>10	------
500	11	------	------
750	13	------	------
1,000	14	------	------
1,500	>14	------	------

[1] Adjusted to 1957–59 index of wholesale prices.

There are two reasons for this rapid rate of growth that distinguish electronic computers from others with industrial applications:

1. The market for computers is not limited to one industry or group of industries, but, rather, it encompasses every facet of business, industry, and government.
2. The unit cost of electronic computers (up to several million dollars) is such that even a limited number of sales generates a substantial sales volume.

The other two innovations have quite different characteristics which also have an important influence on the rate of economic growth. Nuclear power generation, being directly tied to both the consumer and the industrial economy, has an economic potential far greater than either of the other two since total power generation revenues in this country amounted to $14.4 billion in 1964. The restrictions on the economic growth of this innovation are imposed by the occurrence of incremental growth in very large individual steps. For example, just one of the newest nuclear power-generating plants under construction would increase the total power generated by nuclear energy by $10 to $14 million, or 20 to 25 percent of the present level. Since it requires 3 to 5 years to plan and build one nuclear powerplant, this adds a further delay in the rate at which economic growth can occur in this field.

Numerical control is more typical of innovations with industrial applications. Although these machine tools are expensive when equipped with numerical control (up to $500,000 each), their total market is small—$874 million in 1964. Because of this inherent limitation, it is improbable that numerical control could ever achieve a rate of economic growth approaching that of electronic computers or nuclear power generation.

TECHNOLOGICAL CHANGE: MEASUREMENT, DETERMINANTS, AND DIFFUSION

Prepared for the Commission
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Technological Change: Measurement, Determinants, and Diffusion

Part I: INTRODUCTION

This paper is concerned with the measurement of technological change, the determinants of technological change, and the diffusion of innovations. At the outset, two points should be noted. First, my purpose is to summarize the results of the important recent studies in these areas, not to carry out original research. The allotted time did not permit me to go beyond existing studies. Second, a paper of this length must necessarily be selective, the literature on these topics being so voluminous that it would be impossible to cover all aspects of them. The plan of the paper is as follows. Part II is concerned with the measurement of the rate of technological change; part III discusses the process of technological change; and part IV takes up the diffusion of innovations. Part V provides a brief summary of the findings.

Numbers appearing in brackets refer to bibliographic references which are given at the end of the paper.

Part II: MEASURING THE RATE OF TECHNOLOGICAL CHANGE

1. Introduction

This part of the paper, which is devoted to various measures of the rate of technological change, begins in section 2 with a discussion of what economists generally mean by technological change. Section 3 discusses partial productivity indexes and presents data based on such indexes for various industries. Section 4 discusses results based on total productivity indexes, and sections 5 and 6 present estimates of the rate of technological change based on various "production functions," as well as on the assumption that technological change is organizational (sec. 5) or capital-embodied (sec. 6). Section 7 discusses patent statistics. Section 8 considers whether or not these measures provide any evidence of an increase in recent years in the rate of technological change. Section 9 discusses the importance of technological change in the process of economic growth. Section 10 is devoted to a discussion of the limitations of the available measures of the rate of technological change. Findings are summarized in section 11.

2. Technological Change and the Production Function

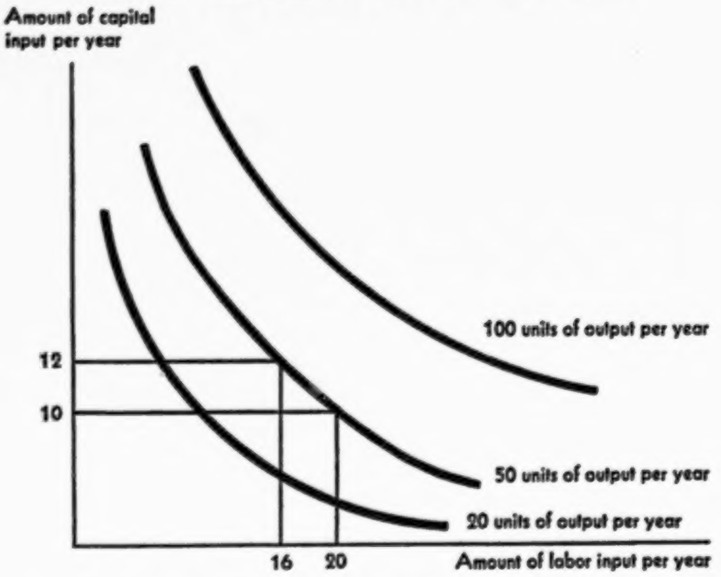
When technological change is mentioned, one ordinarily thinks of a sequence of new products and processes—nylon, catalytic cracking of petroleum, hybrid corn, the B-47, and a host of others. The new processes used and products produced in a particular industry during a given period of time generally vary enormously in effect and importance. To devise an aggregate measure of the rate of technological change in an industry, it is necessary to define more clearly what we mean by technological change. In order to describe what an economist means by this term, we must begin by discussing five basic concepts—production possibilities, factors of production, production function, constant returns to scale, and best-practice techniques.

(1) *Production possibilities.* At any point in time, there exist a number of ways of producing a given product: Some use little capital and much labor, others much capital and little labor; some are cheap, some expensive; some are relatively old, some relatively new. Each alternative method is called a production possibility. Unfortunately, whether or not a given method is a production possibility is not entirely clear cut, since some could be brought to perfection if one wanted to devote a considerable amount of development effort. Although it is somewhat arbitrary, only those methods that are reasonably well explored or that require only a trivial amount of development are included here as production possibilities.

(2) *Factors of production.* These are the inputs required to produce goods—inputs such as labor, materials, equipment, and land. To determine at any point in time which production possibilities are more economical than others, the amount of each factor required to produce a given output must be known for each production possibility. In the case of labor requirements, each type of labor can be regarded as a separate factor of production and its quantity can be measured in man-hours. Materials can be measured in their appropriate technical units (e.g., tons of coal). The measurement of capital is more complicated. Since we are interested in comparing methods in the long run, when every element that is technically variable can be altered, capital can be measured in terms of monetary investment, after making allowance for the length of life of the investment.

(3) *Production function.* This is a relationship between inputs and outputs. The production function is a key concept in the measurement of the rate of technological change. At any point in time it shows the maximum output rate which can be obtained from given amounts of the factors of production. For example, if we assume that there are only two factors of production, capital and labor, figure 1 shows the production function for a particular product at a particular point in time. Each curve pertains to a certain level of output and shows the various combinations of capital and labor that will produce this output. (For example, an output rate of 50 units per year can be achieved by using 20 units of labor and 10 units of capital per year, or by using 16 units of labor and 12 units of capital per year.) Of course, the curve does not show all combinations that can produce a given output. Omitted are those production possibilities that are technically inefficient—in the sense that to produce the given quantity of output, they use more of one factor and at least as much of the other factor than some other process.

FIGURE 1. *Hypothetical Production Function*[1]



[1] Fig. shows only part of the production function. There are curves for output levels other than 20, 50, and 100; but for simplicity they are omitted from the diagram.

(4) *Constant returns to scale.* This means that if all inputs are increased by the same proportion, output also increases by that same proportion. In contrast, if output increases under these conditions by less (more) than the same proportion, we say that there are decreasing (increasing) returns to scale. Figure 2a shows a case of decreasing returns to scale, with an output of 40 units requiring more than double as much capital and labor than an output of 20. Figure 2b shows a case of increasing returns to scale, with an output of 40 units requiring less than double as much capital and labor than an output of 20 units. Figure 2c shows a case of constant returns to scale.

(5) *Best-practice technique.* At a given date this is the one with minimum cost. Figure 3 shows the production function, assuming constant returns to scale. Under these circumstances, labor and capital inputs can be expressed on a requirement-per-unit-of-output basis, with a single curve resulting for all levels of output in the relevant range. To determine the best-practice technique, lines (A, B, and C) can be drawn representing the combinations of quantities of labor and capital that can be purchased for a certain amount. For example, figure 3 shows that the best-practice technique, given the labor cost of $2.50 an hour, uses 32 hours of labor and $120 of capital per unit of output.

In the light of these definitions, the economist, then, defines technological change as *a change in the production function.* Of course, the production function may change for a variety of reasons. An important advance may be made through research of a firm producing the product, by workers in the firm's shops, by a firm supplying materials to the industry, or by an independent inventor. Moreover, the change in the production function may take a variety of forms—improved equipment or material, better organization, etc. But regardless of its source or form, a technological change, according to the economist, is a change in the production function.

Thus, a comparison of the production function at two points in time provides the economist with a simple measure of the extent and character of the technological change that occurred in the intervening period. For example, if the input requirements in 1900 and 1960 were given by curves 1 and 2, respectively, in figure 4, the rate of technical change during that period would have been less rapid than if the input requirements in 1960 were given by curve 3. Indeed, if the curves maintain the same shape over time, it is possible to represent the average rate of technological change during the period, i.e., the average rate of movement of the production function, by a

FIGURE 2. *Illustrations of Decreasing, Increasing, and Constant Returns to Scale*

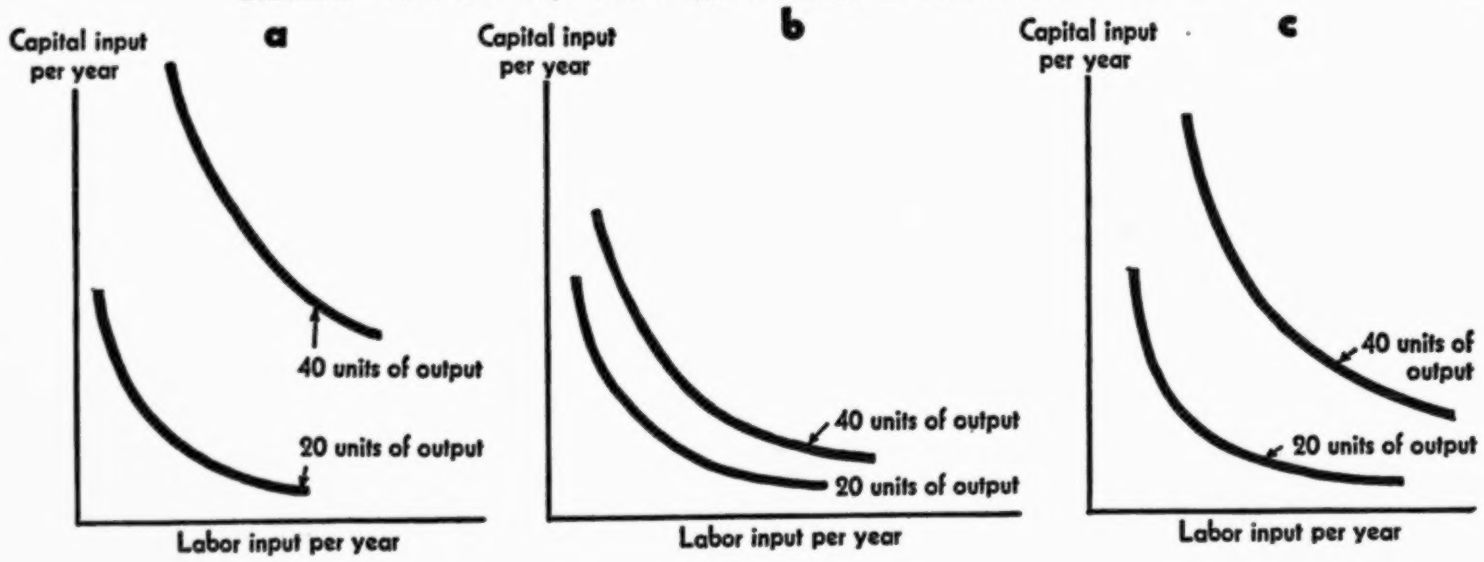
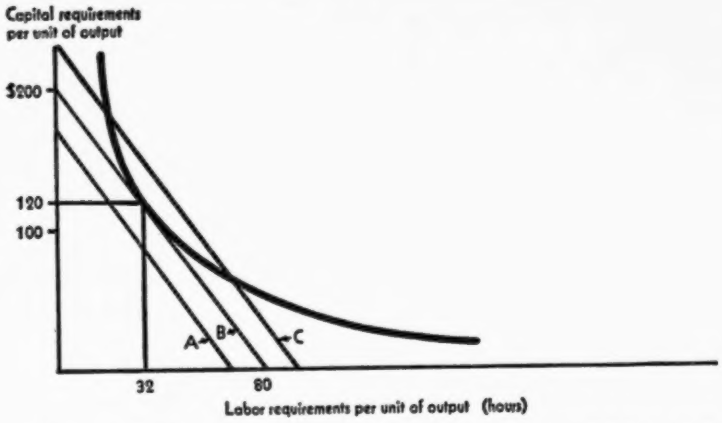


FIGURE 3. *Determinants of Best-Practice Technique* [a]



[a] Lines A, B, and C represent all combinations of labor and capital that can be bought for $175, $200, and $225, respectively. The graph clearly shows that $200 is the minimum unit cost for the product, and that the best-practice technique uses $120 of capital and 32 hours of labor per unit of output.

single number which, as we shall see in subsequent sections, can be estimated under certain circumstances.

Finally, it should be clear that not all changes in best-practice technique are due to technological change. A great many occur, instead, as a consequence of changes in factor prices. For example, if the production function is shown in figure 5 and if the wage rate increases from $2.50 to $3 an hour, the best-practice technique changes from one using 50 hours of labor and $50 of capital per unit of output to one using 40 hours of labor and $77 of capital per unit of output. Yet this change in best-practice technique is obviously not due to technological change, since there has been none here. Turning to a more realistic example, according to Brozen [9], "Detroit automation" has been largely of this variety. Transfer equipment to move work from one automatic machine tool to another and interlocking these tools to get higher utilization was first used in 1927 by Morris Motors but was not economical at the time. That is, it did not correspond to the minimum cost point on the production function. However, now that wage rates have risen and machine tools have become more expensive, it does correspond to the minimum-cost point and consequently it has become a best-practice technique.[1]

FIGURE 4. *Hypothetical Input Requirements at Various Points in Time*

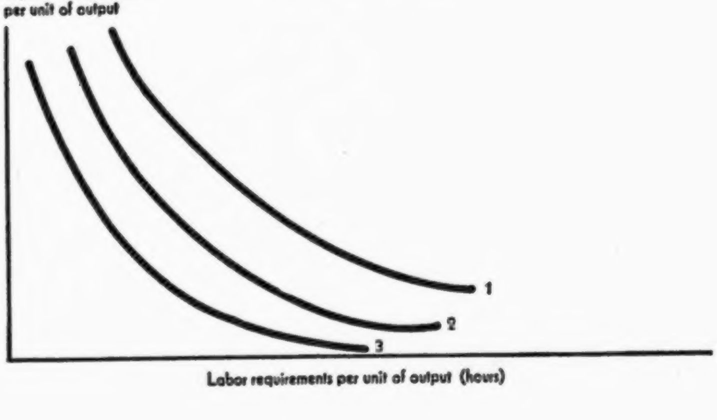
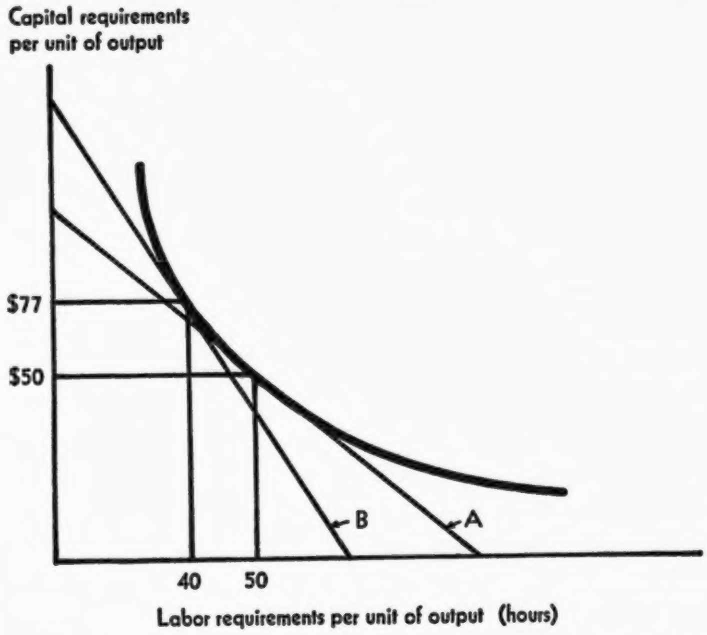


FIGURE 5. *Change in Best-Practice Technique Due to Change in Factor Prices* [1]



[1] Line A represents all combinations of labor and capital requirements per unit of output that can be purchased for the amount of money equal to the minimum unit cost of producing the product, given a wage rate of $2.50. Line B represents the same thing, except that the wage rate is $3.

3. Partial Productivity Indexes and Output per Man-Hour

Two types of productivity indexes, partial and total, are in common use. The oldest and most commonly studied type of partial productivity index is output per man-hour of labor. In addition, there are others; for example, output per dollar of capital input and output per unit of raw material. They are partial in the sense that output is related to one input at a time, without recognition of the changes in the quantity of other inputs. Thus, a rise in labor productivity may be due to the substitution of capital for labor resulting from changes in relative prices, not to technological change. Although output per man-hour is obviously a very incomplete measure of the rate of technological change, as defined in the previous section, it is of considerable interest because higher productivity usually is accompanied by a higher wage rate and standard of living. More sophisticated measures of the rate of technological change will be considered in subsequent sections.

---

[1] Needless to say, it is often extremely difficult to tell whether a given change in best-practice technique is due to technological change or a change in factor prices.

This section presents a very simple and crude description of these concepts. For a much more complete and precise discussion, see Salter [71].

The most comprehensive study of labor productivity in recent years [38] draws the following conclusions: First, during 1889–1957, the Nation's real output per man-hour of work has been rising at an average rate of between 2 and 2.5 percent per year. This substantial upward movement shows no signs of abating. The productivity gains have been widely diffused, real hourly earnings having grown about as rapidly, on the average, as output per man-hour. They have also been used to promote increased leisure, with working hours having been cut by 20 or 30 percent on the average since the turn of the century.

Second, physical output per man-hour in the private economy seems to have grown at an average rate of about 2.4 percent, somewhat higher than the rate of growth of labor productivity in the economy as a whole. The relatively low rate of growth of productivity in government may be due to the fact that measures of government output are extremely poor. For this reason, most economists have more faith in figures for the private economy than for the economy as a whole.

Third, after World War I, the rate of increase of output per man-hour increased. During 1899–1919, output per man-hour rose at an average rate of 1.6 percent per year; during 1920–57, it grew at an average rate of 2.3 percent per year. The reasons for this increase are by no means clear. Kendrick [38] suggests that it may have been due to the spread of the scientific management movement, the expansion of college and graduate work in business administration, the spread of organized research and development, and the change in immigration policy.

Fourth, output per man-hour rose more rapidly during some phases of the business cycle than others. Average year-to-year increases in labor productivity were greater when business was expanding (2.4 percent per year) than when it was contracting (1.3 percent per year). The rate of increase was poorest in the first phases of contraction and highest toward the end of the contraction and the beginning of the expansion. In part, these cyclical changes may reflect the fact that an industry's work force cannot be adjusted instantaneously to changes in demand and that some workers are retained during a recession because of the expectation that business will soon improve.

Fifth, there were considerable differences among industries in the rate of increase of output per man-hour, as shown in table 1. However, it is important to note that these figures are less reliable than the national figures. This is partly because errors tend to cancel out in the more aggregative measures and partly because the output figures for individual industries include supplies from other industries. Thus, changes over time in the extent to which an industry manufactures its own supplies can influence the labor productivity index. In addition, of course, the rate of technological change in one industry results in part from what happens in other industries.

TABLE 1. AVERAGE ANNUAL RATES OF CHANGE OF OUTPUT PER UNIT OF LABOR INPUT, VARIOUS SECTORS OF THE U.S. PRIVATE DOMESTIC ECONOMY, 1899–1953

Sector	Estimate (percent)	Sector	Estimate (percent)
Farming	1.7	Beverages	1.6
Mining	2.5	Tobacco	5.1
Metals	2.6	Textiles	2.5
Anthracite coal	.7	Apparel	1.9
Bituminous coal	1.7	Lumber	1.2
Oil and gas	3.4	Furniture	1.3
Nonmetals	2.9	Paper	2.6
Transportation	3.4	Printing	2.7
Railroads	2.8	Chemicals	3.5
Local transit	2.4	Petroleum	3.8
Residual transport	4.1	Rubber	4.3
Communications and public utilities	3.8	Leather	1.3
Telephone	2.0	Glass	2.7
Telegraph	1.6	Primary metals	2.3
Electric utilities	6.2	Fabricated metals	2.7
Manufactured gas	4.7	Machinery, nonelectric	1.8
Natural gas	3.0	Machinery, electric	2.4
Residual sector	1.4	Transportation equipment	3.7
Manufacturing	2.2		
Foods	1.8		

SOURCE: Kendrick, J., *Productivity Trends in the United States*, Princeton, 1961, pp. 152, 153.

Sixth, a relatively great increase in labor productivity in an industry generally meant lower relative costs and prices and a better-than-average increase in the volume of production. Better-than-average increases in the volume of production were generally accompanied by better-than-average increases in the level of employment, despite the relatively great increase in output per man-hour. Correspondingly, relatively low increases in labor productivity were usually accompanied by less-than-average increases in output and employment.

4. Total Productivity Indexes

The total productivity index relates changes in output to changes in both labor and capital inputs, rather than to changes in labor inputs alone. Specifically, this index equals

$$\frac{q}{zl+vk},$$

where q is output (as a percent of output in some base period), l is labor input (as a percent of labor input in some base period), k is capital input (as a percent of capital input in some base period), z is labor's share of the value of output in the base period, and v is capital's share of the value of the output in the base period. Substituting each period's values of q, l, and k into this formula, one can easily compute the value of the index for each period.[2]

This index has important advantages over the partial productivity indexes, the most important being that it takes account of the change over time in the amount of capital inputs. The substitution of capital for labor will increase output per man-hour, regardless of whether it is due to changes in factor prices or to technological change. The total productivity index is less likely to be influenced by capital-labor substitution due to changes in factor prices. Indeed, if the curves (isoquants) in figure 4 are straight lines, this index provides the "correct" measure of the rate of technological change, i.e., the rate of movement of the production function.[3]

Kendrick [38] used the above formula, or variants of it, to estimate the rate of increase of total productivity in the United States. His principal results are as follows: First, during 1899–1957, total productivity for the private domestic economy increased by about 1.7 percent per year. Second, there seems to have been an increase in the rate of productivity advance to about 2.1 percent per year in the period following World War I. Third, the rate of productivity increase seems to have been higher in communications and transportation than in mining, manufacturing, and farming (table 2). Fourth, within manufacturing it seems to have been highest in rubber, transportation equipment, tobacco, chemicals, printing, glass, fabricated metals, textiles, and petroleum (table 2). Fifth, there was a positive correlation between the rate of growth of output and the rate of productivity increase both by industries and by periods.

In addition, Domar and his associates [19] presented results for the United States, United Kingdom, Germany, Japan, and Canada during the period since World War II. Their findings, presented in table 3, indicate that the rate of increase of total productivity was higher in Germany and Japan than in the United States and Canada, and higher in the United States and Canada than in the United Kingdom. However, if capital inputs had been adjusted for underutilization, the United States, United Kingdom, and Canada might have turned in a better performance. Examination of the results by sector indicates that in Canada and the United Kingdom agriculture and public utilities had the highest rates of productivity increase; in Germany, agriculture; in Japan and the United States, public utilities, transportation, and communication.

TABLE 2. ESTIMATES OF ANNUAL RATE OF INCREASE OF TOTAL PRODUCTIVITY IN VARIOUS SECTORS OF THE U.S. PRIVATE DOMESTIC ECONOMY, 1899–1953

Sector	Estimate (percent per year)	Sector	Estimate (percent per year)
Farming	1.1	Beverages	1.6
Mining	2.2	Tobacco	3.5
Metals	2.2	Textiles	2.4
Anthracite coal	.7	Apparel	1.7
Bituminous coal	1.6	Lumber	1.0
Oil and gas	3.0	Furniture	1.4
Nonmetals	2.6	Paper	2.3
Transportation	3.2	Printing	2.6
Railroads	2.6	Chemicals	2.9
Local transit	2.5	Petroleum	2.4
Residual transport	4.0	Rubber	4.1
Communications and public utilities	3.6	Leather	1.2
Telephone	2.0	Glass	2.6
Telegraph	1.8	Primary metals	1.9
Electrical utilities	5.5	Fabricated metals	2.6
Manufactured gas	4.7	Machinery, nonelectric	1.7
Natural gas	2.0	Machinery, electric	2.2
Residual sector	1.3	Transportation equipment	3.5
Manufacturing	2.0		
Foods	1.7		

SOURCE: Kendrick, J., *Productivity Trends in the United States*, Princeton, 1961, pp. 136–137.

TABLE 3. ESTIMATES OF ANNUAL RATE OF INCREASE OF TOTAL PRODUCTIVITY, UNITED STATES, CANADA, UNITED KINGDOM, GERMANY, AND JAPAN, IN PERCENT

	United States 1948–60	Canada 1949–60	United Kingdom 1949–59	Germany 1950–59	Japan 1951–59
Economy	N.A.	1.2	0.6	3.6	3.7
Private economy	1.4	N.A.	.7	N.A.	3.8
Private nonfarm economy	N.A.	N.A.	N.A.	N.A.	3.9
Sectors:					
Agriculture	2.6	2.0	[1] 2.0	4.3	1.2
Forestry, fishing, trapping	N.A.	.7			
Mining, quarrying, oil wells	N.A.	.9	.3	3.4	−.6
Manufacturing	2.6	1.4	[1].7		4.1
Construction	N.A.	.6	[3].2		2.2
Public utilities	3.4	2.0	[3] 1.9	1.5	4.5
Transportation and communication		1.5	1.8		
Wholesale and retail trade	N.A.	−.6	[2]−1.0		−.5
Finance, insurance, real estate	N.A.	.6	.6	1.4	4.1
Other services		−.8			
Government	N.A.		−2.8		6.7

[1] 1950–59.
[2] 1953–59.
[3] 1950–58.
N.A.=Not available.

SOURCE: Domar E., S. Eddie, B. Herrick, P. Hohenberg, M. Intrilligator, and I. Miyamoto, "Economic Growth and Productivity in the United States, Canada, United Kingdom, Germany, and Japan in the Post War Period," *Review of Economics and Statistics*, February 1964, table 6.

5. Rates of Organizational Technological Change

The total productivity indexes assume implicitly that the isoquants in figure 4 are straight lines, which in turn implies that the extra production resulting from the addition of an extra man-hour of labor is independent of the amount of capital used. The curves in figure 4 seem more reasonable.[4] Economists have made a number of estimates of the rate of technological change based on assumptions compatible with isoquants having this more reasonable shape.

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[2] This formula comes from Domar [17], who provides a valuable commentary on Kendrick's book [38]. For an alternative definition of the total productivity index, see Domar's eq. (3).

[3] That is, it represents a correct measure if the production function is $Y(t)=C(t)[al(t)+bK(t)]$, where $Y(t)$ is deflated output at time t, $l(t)$ is labor input in physical terms at time t, $K(t)$ is capital input in physical terms at time t, a and b are constants, and $C(t)$ represents an index of technology. See Domar [17].

[4] For an elaboration of this point, see Domar [17], p. 601.

Solow [79], in an important paper published in 1957, provided an estimate of the rate of technological change for the nonfarm economy during 1908–49. He assumed constant returns to scale, that capital and labor were paid their marginal products,[5] and that technological change was neutral.[6] The results suggest that for the entire period the average rate of technological change was about 1.5 percent per year, but there is some evidence that the

> average rate of progress in the years 1909–29 was smaller than that from 1930–49. The first 21 relative shifts average about nine-tenths of 1 percent per year, while the last 19 average 2.6 percent per year. Even if the year 1929, which showed a strong downward shift, is moved from the first group to the second, there is still a contrast between an average rate of 1.2 percent in the first half and 2.3 percent in the second.[7]

Massell, in an article published in 1960 [55], presented a similar sort of estimate for U.S. manufacturing. Aside from his study having pertained to a much smaller portion of the entire economy, the main differences from Solow's procedure were in Massell's time period (1919–55) and his use of a somewhat more sophisticated technique to adjust capital stock figures to reflect idle capital. Massell's estimate of the annual rate of technological change for manufacturing during this period was about 2.9 percent. In contrast with Solow, his results show little or no evidence of a higher rate of technical change during the thirties and forties than in previous decades. Massell attributes this difference to discrepancies in the ways in which he and Solow adjust the capital stock figures for idle capacity.

Arrow, Chenery, Minhas, and Solow [5] obtained an estimate of the rate of technological change for the nonfarm economy, based on Solow's figures for 1909–49, and somewhat different assumptions about the shape of the curves in figure 4. Their result was 1.83 percent, which agrees pretty well with Solow's estimate of 1.5 percent.

The studies described thus far in this section were concerned with very large and heterogeneous segments of the U.S. economy. Further studies have been carried out to estimate the rate of technological change for somewhat smaller, more homogeneous units. Ando [2] has provided estimates for the consumption-goods and the capital-goods industries in the United States during 1901–28 and 1951–57. Of course, any separation of census or other industries into these two categories is bound to be rough, but the results are nonetheless of considerable interest. According to his findings, the rate of technological change equaled about 1.3 percent in both industries in 1901–28. During 1951–57, it was about 1.7 percent in the consumption-goods industry and about 1.2 percent in the capital-goods industry.

Massell's results, shown in table 4, pertain to 1946–57. The estimates of the rate of technological change vary from 3.8 percent in lumber to 0.3 percent in fabricated metal products, the weighted average (weighting by an industry's output) being 1.9 percent.

> At first glance one is perhaps surprised to find lumbering at the top of the list . . . and primary and fabricated metal products at the bottom . . . . The peculiarity of these results could be an indication of nonneutral technical change in these industries.[8]

TABLE 4. ESTIMATES OF THE RATE OF TECHNOLOGICAL CHANGE, TWO-DIGIT MANUFACTURING INDUSTRIES, 1946–57

Industry	Estimate (percent per year)	Industry	Estimate (percent per year)
Lumber and wood products	3.8	Textile mill products	1.6
Electrical machinery	3.7	Food and kindred products	1.4
Chemicals and products	3.5	Leather and leather goods	1.1
Stone, clay, and glass products	2.5	Rubber products	1.0
Printing and publishing	2.4	Furniture and fixtures	1.0
Transportation equipment	2.4	Instruments and related products	1.0
Pulp, paper, and products	2.3	Apparel and related products	.9
Machinery, except electrical	2.0	Tobacco manufacturers	.8
Petroleum and coal products	1.9	Primary metal products	.4
		Fabricated metal products	.3

SOURCE: Massell, B., "A Disaggregated View of Technical Change," *Journal of Political Economy*, 1961, p. 554.

Finally, other studies of individual industries have been made by Liu and Hildebrand [44], Ferguson [23], Dhrymes and Kurz [16], and Griliches [27]. Unfortunately, space does not permit discussion here.

6. Rates of Capital-Embodied Technological Change

In previous sections technological change was implicitly assumed to be organizational, i.e., all technological progress consists of better methods and organization that improve the efficiency of both old capital and new. Examples of such improvements can be found in various advances in industrial engineering (e.g., the use of time and motion studies) and operations research (e.g., the use of linear programing). Although technological change of this sort has undoubtedly been important, it is clearly not the only type that has occurred. On the contrary, many changes in technology must be capital-embodied if they are to be utilized. For example, the introduction of the continuous wide strip mill in the steel industry and the diesel locomotive in railroads required new investment in plant and equipment. No one really knows the extent to which technological change in recent years has been capital-embodied, but the available evidence seems to indicate that a great deal has been of this kind.

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[5] That is, a factor of production receives payment equal to the value of the extra production for which it is responsible. See, for example, J. Bain, *Pricing Distribution and Employment*, Holt, 1953.

[6] If technological change is neutral, the production function may be written as $Y(t)=C(t)f[1(t), K(t)]$, where the symbols are defined in note 3 above. See Solow [79].

[7] Solow [79], p. 316. The 2.6- and 2.3-percent figures reflect subsequent correction in data.

[8] Massell [56], p. 554.

If technological change is assumed to be capital-embodied and not organizational, somewhat different methods should be used to estimate the rate of technological change. In a study based on capital-embodied change published in 1959, Solow [80] estimated that the rate of technological change in the private economy during 1919–53 was 2.5 percent per year, higher than his earlier estimate based on the assumption that technological change was organizational.

Turning to individual industries, Mansfield [45] estimated the rates of capital-embodied technological change in 10 two-digit manufacturing industries during 1946–62. The results, shown in table 5, suggest that it was highest in motor vehicles and instruments; next highest in food, chemicals, electrical equipment, paper, and apparel; and lowest in machinery, furniture, and glass. As expected, the estimated rates of capital-embodied technological change generally exceed the estimated rates of organizational technical change, shown in table 4.[9] There is relatively little correlation between them, but both sets of estimates contain substantial sampling errors. Mansfield [46] also estimated that the rate of capital-embodied technological change in the railroad industry during 1917–59 was 3 percent per year.

TABLE 5. ESTIMATES OF RATE OF CAPITAL-EMBODIED TECHNOLOGICAL CHANGE, 10 TWO-DIGIT MANUFACTURING INDUSTRIES, 1946–62

Industry	Estimate (percent per year)	Industry	Estimate (percent per year)
Chemicals	3.7	Electrical equipment	3.6
Machinery	(1)	Stone, clay, and glass	1.5
Food	4.7	Furniture	1.9
Paper	3.4	Apparel	3.0
Instruments	8.3	Motor vehicles	8.6

[1] Less than zero.

SOURCE: Mansfield, E., "Rates of Return from Industrial Research and Development," *American Economic Review*, May 1965.

Finally, let us turn to estimates of the rate of technological change in individual firms. Mansfield [45] has provided estimates for 10 large chemical and petroleum firms in the postwar period, with one set assuming that technological change was organizational, the other assuming that it was capital-embodied. The results are shown in table 6. In part III of this paper, some hypotheses will be examined that may explain observed differences among firms in the rate of technological change.

TABLE 6. ESTIMATES OF THE RATE OF TECHNOLOGICAL CHANGE, ORGANIZATIONAL AND CAPITAL-EMBODIED, 10 CHEMICAL AND PETROLEUM FIRMS, 1946–62

Firm [1]	Organizational (percent per year)	Capital-embodied	Firm [1]	Organizational (percent per year)	Capital-embodied
C1	0.4	0.5	P1	0.3	2.1
C2	2.4	6.2	P2	1.9	5.9
C3	2.6	2.0	P3	3.2	6.6
C4	1.4	3.5	P4	1.1	9.5
C5	(2)	5.3	P5	1.8	8.8

[1] Basic data were obtained from the firms with the understanding that firm names would not be divulged. Thus, C1 stands for the first chemical firm, P1 stands for the first petroleum firm, etc.
[2] Less than zero.

SOURCE: Mansfield, E., "Rates of Return from Industrial Research and Development," *American Economic Review*, May 1965.

7. Patent Statistics

The number of patents issued is sometimes used as a crude index of the rate of technological change. Whether such statistics are used as a measure of inventive input or output, they are obviously a very slim reed on which to base conclusions. For one thing, the average importance of the patents granted at one time and place may differ from those granted at another time and place. For another, the proportion of the total inventions patented may vary considerably. Nonetheless, it is of interest to see what the patent statistics suggest.

Studies of patent statistics indicate at least four things: First, as an industry grows older, the rate of patenting tends to increase first at an increasing rate, then at a decreasing rate, and finally to decline. More specifically, the amount of patenting seems to be highly correlated with the output and investment of the industry. Kuznets [42] and Merton [57] showed that this was the case for typewriters, sewing machines, plows, electrical appliances, cotton machinery, weaving machinery, spinning machinery, telegraphy, telephony, automobiles, airplanes, and radio. Stafford's more extensive study [81] yielded further support for this hypothesis, as did Schmookler's study [74] of the railroad, petroleum refining, horseshoe, and construction industries.

Second, according to Griliches and Schmookler [30], the patent rate in an industry tends to lag behind its output rate. Correlating the number of patents on processes in an industry with value added 3 years before, they found that 84 percent of the variation in the patent rate could be explained. Third, turning from individual industries to the entire economy, the number of patents granted per year tends to rise and fall with the business cycle. For the United States as a whole, Graue [26] found considerable correlation, after removing trends from both series, between the level of industrial production and the number of mechanical patents issued. Schmookler [76] found a significant correlation between patent applications and variable production inputs, both expressed as deviations from trend.

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[9] For reasons why the rates of capital-embodied technological change would be expected to exceed the rates of organizational technological change, see E. Phelps "The New View of Investment, *Quarterly Journal of Economics*, November 1962.

Fourth, turning from comparisons over time to those among industries at a given point in time, the number of patents tends to be directly related to the value added in an industry. That is, industries with high value added account for more patents than those with low value added. Schmookler and Brownlee [77], using data for 18 manufacturing industries, show that this relationship is quite strong, particularly when the patent data are lagged several years behind the value added data. (The coefficient of correlation, which is higher in more recent years, exceeded 0.9 in 1947.) Moreover, Griliches and Schmookler [30] show that this relationship persists when the effects of industry size are taken into account.

8. Has There Been an Increase in the Rate of Technological Change?

Using the measures described above, is there any evidence that technological change is occurring more rapidly now than in the past? This is a very important question, bearing on a number of the major issues and problems facing the Commission. It is easy to find statements by economists and others asserting that the rate of technological change in the postwar period is much more rapid than before the war, and it is equally possible to find statements asserting the opposite. For example, John Diebold [15] has stated that "... the aggregate productivity figures would not reveal any abnormally high productive influence in the postwar economy," [10] and Lee DuBridge [20] has asserted that"... the recent introduction of automation has produced no radical change in trend." [11]

The primary evidence on this score is of three types. First, we can point to studies of the behavior of output per man-hour. According to Ewan Clague and Leon Greenberg [11], the average rate of increase of output per man-hour in the total private economy during 1947–61 was 3 to 3.3 percent, depending on the source of the data, whereas the 1909–61 average was 2.4 percent. According to Kendrick and Sato [39], the average rate of increase of output per man-hour in the private domestic economy was 2.84 percent during 1948–60, as compared with 2.36 percent during 1919–60. According to the Council of Economic Advisers [13], the average rate of increase during 1947–63 was 3.2 percent, as contrasted with 2.2 percent during 1919–47. Thus, regardless of which study one cites, the rate of increase of output per man-hour in the postwar period seems higher than that before the war.

Second, we can point to studies to determine whether the relatively high rates of increase in output per man-hour during 1961–63 can be explained by cyclical and transitory factors affecting productivity. The Council of Economic Advisers [13] carried out several statistical analyses of nonfarm productivity gains of 1949–60 to estimate the effects on productivity of the average age of equipment, the rate of growth of output, and the degree of capacity utilization. Findings were then used to estimate the increases in productivity that might have been expected in 1961–63 if the past relationship held. The results suggested that the increases in 1961–63 were either about equal to the expectation or in excess of it by amounts ranging up to 1 percentage point.

Third, we can point to studies based on total productivity indexes and on indexes based on other assumptions regarding the shape of the production function. For reasons given in section 4 above, these indexes are generally superior to output per man-hour. Kendrick and Sato [39] find that the average annual rate of increase of total productivity in the private domestic economy during 1948–60 was 2.14 percent, as compared with 2.08 percent during 1919–60. Assuming that technological change was organizational, Nelson [61] estimated the average rate of technological change as 1.9 percent in 1929–47, 2.9 percent in 1947–54, and 2.1 percent in 1954–60. Assuming technological change was capital-embodied and taking changes in labor quality roughly into account, it averaged 1.5 percent in 1929–47, 2 percent in 1947–54, and 1.2 percent in 1954–60. Thus, there is some evidence that the rate of technological change has been higher since World War II, but the difference is much smaller than that indicated by the behavior of output per man-hour.

Thus, according to the studies cited here, the rate of increase of output per man-hour has been greater after World War II than before. Using more sophisticated measures of the rate of technological change, the difference between the pre- and postwar periods is smaller but usually in the same direction. However, these measures are rough, a point that must be emphasized and which will be elaborated further in section 10 below.

9. Technological Change and Economic Growth

Another important question, which has been of considerable interest to economists and which bears on the Commission's task, is to what extent has the economic growth of the United States been due to granted per year tends to rise and fall with the business cycle. For the United States as a whole, Graue [26] found considerable correlation, after removing trends from both series, between the level of industrial production and the number of mechanical patents issued. Schmookler [76] found a significant correlation between patent applications and variable production inputs, both expressed as deviations from trend.

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[10] Diebold [15], p. 48 of *Automation*, edited by M. Philipson, Random House, 1962.

[11] DuBridge [20], p. 31.

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9. Technological Change and Economic Growth

Another important question, which has been of considerable interest to economists and which bears on the Commission's task, is to what extent has the economic growth of the United States been due to technological change? The U.S. rate of economic growth has occupied an important place in the press and in speeches by academicians, civil servants, businessmen, and labor leaders. An important issue in the 1960 presidential election, it has remained in the public eye throughout the sixties.

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[10] Diebold [15], p. 48 of *Automation*, edited by M. Philipson, Random House, 1962.

[11] DuBridge [20], p. 31.

In the baldest terms, the rate of economic growth is the rate at which the production of goods and services is increased per capita. Economists and others generally feel that it is desirable for the United States to maintain a high rate of economic growth. Beyond the obvious reason that the rate of increase of a people's standard of living is of importance, three major arguments are made in support of this view: First, the cold war requires that we maintain our economic lead over the Soviet Union; second, we have many unmet domestic needs—for example, for more and better schools, more extensive and better public health, further urban redevelopment, and better urban transportation—and, barring an increase in the ratio of public to private expenditures, the rate at which these needs can be met is dictated by the rate of economic growth; third, to expand at the needed rate our contribution to the economic development of the poorer nations, we must accelerate our own rate of economic growth.

Over the relatively long run, our rate of economic growth has compared favorably with most other countries, but during the fifties our 2.2 percent rate compared less favorably with 6.1 percent for Japan, 4.7 percent for Italy, 4.5 percent for Germany, 3.6 percent for France, and 2.8 percent for Sweden. Only the United Kingdom, with a 1.7 percent rate was lower.[12] Accepting the arguments for a high rate of economic growth and confronted by what seemed to be relatively poor performance in this regard, the Administration repeatedly expressed concern over the situation. On November 17, 1961, the United States joined with other members of the Organization for Economic Cooperation and Development (OECD) in setting as a target the attainment of a 4.1-percent annual increase in GNP during 1960–70. In its 1964 annual report, the President's Council of Economic Advisers pointed out that to meet this target, total output "will need to grow at an average annual rate of 4.2 percent in the next 7 years. That rate is within our grasp."[13]

Given the desire in the United States and elsewhere to increase the rate of economic growth, it was only natural that economists would try to determine the effects of various factors on the economic growth rate. Clearly, the basic determinants of the rate of increase of potential output were: (1) The rate of increase in quantity and quality (health, education, motivation, etc.) of the labor force, (2) the rate of increase in the stock of plant and equipment, as well as its distribution by age, type, and location, (3) the rate of increase or decrease in the natural resources accessible to the economy, (4) the changes in efficiency in allocating resources (due to changes in the extent of monopolistic and other barriers to the movement of labor and capital), and (5) the rate of technological change.

Because of the complex interaction among these factors, it has proved very difficult to estimate from historical statistics the relative importance of each. Nonetheless, a number of important and influential attempts have been made. Fabricant [22] estimated that about 90 percent of the increase in output per capita during 1871–1951 was attributable to technological change, increased educational levels and other factors not directly associated with increases in the quantity of labor and capital. Using more sophisticated techniques, Solow [79] estimated that about 87 percent of the increase in output per man-hour was due to these factors. The most recent, and also the most exhaustive study in this area, was carried out in 1962 by Edward Denison [14], who concludes that the "advance of knowledge" contributed about 36 percent of the total increase in national income per person employed during 1929–57. He estimated the contributions of other factors as: Increase in total inputs per person employed (including education), 42 percent; and economies of scale, 21 percent.[14]

These estimates undoubtedly are correct in indicating that technological change played a major, perhaps the most important, role in generating economic growth. Beyond this, their accuracy cannot be taken very seriously for at least three reasons: First, the effects of technological change are measured entirely by the growth of output unexplained by other factors, the consequence being that they are mixed up with the effects of whatever inputs are not included. Second, the use of GNP as a measure of output has a number of important disadvantages and misses some of the most important effects of technological change, for example, on leisure and the spectrum of choice. Third, these studies fail to recognize the full interdependence of technological change, education, and physical capital with the result that the estimated contribution of each may not be a good indication of the sensitivity of the growth rate to an extra investment in any one of them.

10. Problems in the Measurement of Technological Change

It is important to review some of the problems posed by the existing measures of the rate of technological change. First, because these measures equate the effect of technological change with whatever increase in output is unexplained by other factors, they do not isolate the effects of technological change alone. In addition, they contain the effects of whatever factors are excluded; for example (depending on the particular study), increases in education, betterment of worker health and nutrition, economies of scale, changes in product mix, or improved allocation of resources. Thus far, economists have been unable to sort out the effects of "pure" technological change, except perhaps when dealing with individual processes.[15]

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[12] These figures are from the *Economic Review* of the National Institute of Economic and Social Research, July 1961.

[13] Council of Economic Advisers [13], p. 53. Of course, inflation has become an important issue in recent months.

[14] Denison [14], p. 270.

Second, there are a number of well-known problems regarding the meaningfulness and usefulness of the production function, a concept that lies at the heart of these measures. As Joan Robinson [66] has often stressed, the measurement of aggregate capital is a tricky, if not impossible, business. Samuelson [72] has provided some rationalization for the use of a simple production function which treats capital as a single entity, when in fact many heterogeneous varieties of capital exist, but this rationalization is possible only under a limited set of circumstances.

Third, the customary measures often assume that there are no economies of scale and that technological change is neutral. The dangers in these assumptions have been stressed by Stigler [82], Hicks [32], Mansfield [47], and others. The common assumption that the elasticity of substitution[16] equals one has also been questioned, and there has been some reaction recently against the usefulness of the capital-embodied technical-change hypothesis, as generally put forth. For details, see Griliches [27], Jorgenson [35], and Nerlove [64].

In summary, available measures pose many important problems and should be used only as very rough guides. We are a long way from having accurate measurements of the rate of technological change.

11. Summary and Conclusion

The principal points made in part II can be summarized as follows: First, economists define technological change as a shift in the production function, the production function being the relationship in a given firm or industry between the quantity of various inputs (capital, labor, land, etc.) and the maximum output that can be produced. On the basis of various simplifying assumptions regarding the nature of the production function and the way it shifts over time, economists have been able to devise techniques to measure the rate at which it shifts. The result typically is a single number, "x percent per year;" that is, the quantity of output derivable from a fixed set of inputs has increased at x percent per year.

Second, two types of productivity indexes—partial and total—are in common use. The most common form of partial productivity index is output per man-hour, and an important disadvantage of this index as a measure of technological change is its failure to take any account of changes in inputs over time other than labor. A better measure is the total productivity index which relates changes in output to changes in both labor and capital. However, the total productivity index unfortunately assumes implicitly that isoquants are straight lines. To remedy this, economists have devised a number of measures of the rate of technological change based on more reasonable assumptions regarding the shape of isoquants. Some of these measures assume that technological change is organizational; others assume that it is capital-embodied.

Third, using any of these measures, the level of technology seems to have increased considerably in the United States throughout this century, the average rate of technological change being 1.5 to 2.5 percent per year, depending on the measure used. The rate of technological change seems to have varied perceptibly over time. Regardless of which measure is used, there is considerable evidence that the rate of technological change was higher after World War I than before, and some evidence that it was somewhat higher after World War II than before, although the latter is by no means a certainty.

Fourth, the rate of growth of total productivity seems to have varied considerably among both industries and nations. Over the long run, it seems to have been higher in communications and transportation than in mining, manufacturing, and farming. Within manufacturing, it seems to have been highest in rubber, transportation equipment, tobacco, chemicals, printing, glass, fabricated metals, textiles, and petroleum. Comparing the United States with Germany, Japan, Canada, and the United Kingdom during the postwar period, our rate of productivity growth seems lower than that of Germany and Japan, but at least equal to that of Canada and the United Kingdom.

Fifth, these measures of the rate of technological change have been used to estimate the relative importance of technological change in the process of economic growth. Studies carried out about a decade ago estimated that about 90 percent of the long-term increase in output per capita in the United States was attributable to technological change and other factors not directly associated with increases in the quantity of labor or capital.

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[15] For this reason, it has become fashionable for economists to refer to total productivity indexes and similar measures as residuals, thus making it plain that these indexes contain more than the effects of technological change. See Domar [17].

It is also very difficult to take proper account of new products and product improvements in existing measures.

[16] For example, see Arrow et al. [5].

A more recent study concludes that the "advance of knowledge" contributed about 36 percent of the total increase in national income per person employed during 1929–57. These estimates undoubtedly are correct in indicating that technological change played a major, if not the most important, role in generating economic growth, but beyond this, their accuracy cannot be taken very seriously.

Finally, even the most sophisticated of these measures of the rate of technological change suffers from very important limitations. Because technological change is measured by its effects, and because its effects are measured by the growth of output unexplained by other factors, it is impossible to sort out technological change from the effects of whatever inputs are not included explicitly in the analysis. In addition, the customary measures suffer from the fact that they focus attention exclusively on the effects of technological change on output, narrowly defined. The available measures are very imperfect guides.

Part III: DETERMINANTS OF THE RATE OF TECHNOLOGICAL CHANGE

1. Introduction

We shall now go behind measurements of the rate of technological change and attempt to answer various important questions regarding the way technological change occurs and the factors determining its pace. Section 2 is concerned with the sources of important inventions, and sections 3 and 4 discuss the factors that determine an industry's rate of technological change. Sections 5 through 7 deal with the amount of research and development financed or performed by Federal agencies and private industries. Section 8 discusses industrial decisionmaking regarding research and development, and sections 9 and 10 are concerned with various characteristics of industrial research and development expenditures. Section 11 discusses the feeling shared by a number of economists that there is an underinvestment or malallocation of R. & D. expenditures. Section 12 takes up the relationship between market structure and technological change, and section 13 summarizes the findings.

2. The Sources of Invention

Despite the many attempts to administer the last rites to the independent inventor, he is by no means dead. Over the last 60 years, it appears that he has contributed a great many important inventions, particularly in industries not directly connected with the sciences. In their study of 50 significant 20th century inventions, Jewkes, Sawers, and Stillerman [34] estimated that over half were produced by individuals not doing company-directed research. Nonetheless, this century has seen a notable shift in the source of inventions away from the independent inventor and toward the corporation. In 1900, about 80 percent of all patents (excluding those issued to the Government) were issued to individuals; in 1957 about 40 percent were issued to individuals. The reasons for this shift are not difficult to find: Technology in most industries has become more complex; a division of labor among specialists in various scientific fields has become more necessary; and the instruments required to research and develop new processes and products have become more expensive.

Patent statistics have been used to study the occupational, educational, and age characteristics of inventors, as well as to measure the rate of inventive activity. Schmookler [75] investigated the occupational characteristics of a random sample of about 100 persons granted patents in 1953. His results indicate that about 60 percent were engineers, chemists, metallurgists, and directors of research and development, and that most of the rest were non-R. & D. executives; almost none were production workers. These figures agree very closely with an earlier study of over 700 inventors made by Rossman [69]. Schmookler also concludes that

> as a rough approximation, only about 40 percent of the inventors taking out patents in a given month are full-time inventors (research and development technologists), about 20 or 25 percent are industrial personnel hired partly to invent, and about a third are completely independent inventors.[17] [75]

With regard to educational background, an estimated 16 percent of those answering had not completed high school, 24 percent had completed high school but had not completed college, 31 percent had finished college but had gone no further, and 25 percent had gone on to do graduate work.[18] Thus, although most had at least a college education, over one-third had no more than a high school education. Of course, these results should be viewed with caution since they are based on a relatively small sample.

Turning to the age of inventors, Lehman [43] has made a very interesting study. Adjusted for the relative number alive at various ages, the mean age of inventors when they made "very important" inventions was 30 to 34 years, and the mean age when "important" inventions were made was about 37 years. Thus, the most significant inventions seem to be largely the product of relatively young men.

Finally, there is a growing literature on "creativity," a subject which has attracted the attention of psychologists in recent years. To measure creativity, they use the ratings or judgments of experts or special tests. Numerous studies of the relationship of various factors with creativity have been made. Unfortunately, although these studies are extremely interesting, they are sorely handicapped by measurement problems. For a recent review of the relevant literature, see Golann [25].

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[17] Schmookler [75], p. 333.

[18] Five percent were in a special category—trade schools, business colleges, etc. For this reason percentages do not add up to 100.

3. Determinants of the Rate of Technological Change

The rate of technological change in an industry depends to a large extent on the amount of resources devoted by members of the industry and Government to the improvement of the industry's technology. The amount of resources devoted by Government depends on how closely the industry is related to the defense, medical, and other social needs for which the Government assumes primary responsibility, on the extent of the external economies generated by the relevant R. & D., and on political factors of various kinds. The amount of resources devoted by private industry depends heavily on potential profitability, with at least two kinds of evidence supporting this proposition. First, econometric studies (noted in sec. 8 below) indicate that the expected profitability of R. & D. projects influences the amount a firm spends on R. & D., and that the probability of its accepting a particular R. & D. project depends on expected returns. Second, case studies of particular inventions and studies of patent statistics seem to support this view.[19]

What, then, determines the profitability of an R. & D. investment? First, ignoring for the moment the costs of making the technological change, it depends on the returns the investor expects, which depend in turn on the characteristics of the technological change and the industry. If a prospective change in technology reduces the cost of a particular product, the (gross) returns from effecting this technical change are likely to be higher if demand for the product is rising rapidly and capacity is being expanded than if demand is constant or falling. Similarly, returns are likely to be higher if the inputs saved by the technological change are expensive and in short supply rather than cheap and plentiful.

Second, it depends on the cost of making the prospective technological change. Obviously, the attempt to solve a given problem depends on whether people think it can be solved, on how costly the solution will be, and on the payoff if it is successful. The cost of making technological changes related to more basic science depends on the number of scientists and engineers existing in relevant fields and on advances in basic science. The amount of effort devoted to making gradual, small-scale improvements depends on the size of the industry, and perhaps its growth rate as well.

Third, the profitability of the investment depends on the industry's market structure and the legal arrangements under which the industry operates. With regard to market structure, there has been considerable argument over the effects of monopolistic power on the profitability of innovation, some claiming that such power increases it, others arguing the contrary. Some tentative conclusions on this are presented in section 12 below. The effects of legal arrangements are often more obvious. For example, the profitability of R. & D. certainly was increased by the 1954 change in the tax laws which permitted R. & D. expenditures to be deducted as a current expense rather than being treated as a capital investment.

In addition to being influenced by the quantity of resources devoted to improving its technology, an industry's rate of technological change depends on the effectiveness with which these resources are used, and the quantity of resources devoted to the improvement of their technology by other industries (particularly those that supply relevant components and materials). Thus, all other things equal, the rate of technological change in an industry is related directly to the effectiveness of the inventive efforts to improve its technology and the extent of the spillover of technology from other industries.

4. Quantitative Effects of Various Factors on the Rate of Technological Change

This section describes the results of the two principal empirical studies of the effects of various factors on the rate of technological change [83], [45]. Terleckyj investigated the relationship between changes in total productivity and 10 explanatory variables for 20 two-digit manufacturing industries. Using various correlation techniques, he concluded that three variables were significantly related to an industry's rate of technological change as measured by changes in total productivity. These explanatory variables were (1) rate of change of output level, (2) amplitude of cyclical fluctuation, and (3) ratio of R. & D. expenditures to sales (or ratio of R. & D. personnel to total man-hours worked).

Terleckyj's results confirm the expectation, based on the previous section, that industry's rate of technological change would be influenced by the size of its R. & D. expenditures. He found that the rate of technological change increases on the average by 0.5 percent for each tenfold increase in the ratio of R. & D. expenditures to sales. Terleckyj's results also seem to confirm the hypothesis that an industry's rate of technological change would be related to the growth of its output level. He found the rate of technological change increasing on the average by 1 percent for every 3-percent increase in growth rate. In addition, Terleckyj found that the rate of technological change was inversely related to the extent of the cyclical fluctuation of an industry. However, this variable, which may reflect the fact that a certain degree of organizational stability is conducive to innovation, is less important quantitatively than the others.

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[19] For example, see M. Peck, "Inventions in the Postwar American Aluminum Industry," T. Marschak, "Strategy and Organization in a System Development Project," and R. Nelson, "The Link Between Science and Invention: The Case of the Transistor," all in *The Rate and Direction of Inventive Activity*, Princeton, 1962.

Mansfield's results, based on the behavior of 10 large chemical and petroleum firms and 10 two-digit manufacturing industries in the postwar period, indicate that for both firms and industries, the rate of technological change is directly related to the rate of growth of their cumulated R. & D. expenditures. If technological change is organizational, the average effect of a 1-percent increase in the rate of growth of cumulated R. & D. expenditures is a 0.1- or 0.2-percent increase in the rate of technological change. If technological change is capital-embodied, it is a 0.7-percent increase in the rate of technological change. Unlike Terleckyj, Mansfield found no significant evidence that the rate of technological change was directly related to an industry's or firm's growth rate.

5. R. & D. Expenditures: Growth and Flow of Funds

Total R. & D. expenditures in the United States have increased tremendously during the last decades. In 1945, industry performed about $1.2 billion worth of R. & D.; in 1962, this figure had increased to about $10.8 billion. In 1945, about $400 million of R. & D. was performed by Government; by 1962, it performed about $2 billion of R. & D. In 1945, the universities and other nonprofit organizations performed about $200 million; in 1962, it rose to about $1.8 billion. Table 7 shows the truly phenomenal rate of growth of R. & D. during the forties and fifties in the United States.[20]

Along with the increase in R. & D. expenditures, there has been a great increase in the number of engineers and scientists engaged in research and development. In 1941, there were fewer than 90,000; in 1961, there were almost 400,000 (table 7). Although their numbers have increased at an impressive rate, they have not kept up with R. & D. expenditures, primarily because the increasing demand for research personnel has resulted in higher salaries, and less skilled labor and equipment seem to have been substituted, where possible, for engineers and scientists.

TABLE 7. TOTAL R. & D. EXPENDITURES AND NUMBER OF RESEARCH SCIENTISTS AND ENGINEERS, UNITED STATES, 1941–62

Year	Total R. & D. expenditures (millions)	Number of research scientists and engineers (thousands)	Year	Total R. & D. expenditures (millions)	Number of research scientists and engineers (thousands)
1941	$900	87	1951	$3,360	158
1943	1,210	97	1954–55	5,620	223
1945	1,520	119	1958–59	11,130	327
1947	2,260	125	1960–61 [1]	13,890	387
1949	2,610	144	1961–62 [1]	14,740	N.A.

[1] Preliminary.
N.A.=Not available.

SOURCE: *The Growth of Scientific Research and Development*, Department of Defense, 1953, pp. 10 and 12; *National Science Foundation Reviews of Data on Research and Development*, No. 33, April 1962, and No. 41, September 1963.

It is also important to note that much of the R. & D. performed by one sector is financed by another. Table 8 shows that a large and increasing percentage of the R. & D. performed in the industrial, university, and nonprofit organization sectors is financed by the Federal Government. In 1953–54, about 40 percent of industrial R. & D. was financed by the Government; in 1961–62, about 60 percent. In 1953–54, about 60 percent of the universities' R. & D. was financed by the Government; in 1961–62, about 75 percent. In addition, a large and relatively stable portion, about 60 percent, of the R. & D. carried out by other nonprofit organizations was Government-financed.

Besides this massive outflow of funds from the Federal Government to support R. & D. performed in other sectors, there were lesser flows from industry and nonprofit organizations other than universities. In recent years, industry financed about 3 percent of the R. & D. carried out by universities and about 25 percent of that carried out by other nonprofit organizations. Other nonprofit organizations financed about 5 percent of the R. & D. performed by colleges and universities.

6. R. & D. Expenditures by the Federal Government

Table 8 shows that the Federal Government finances most of the R. & D. performed in the United States—65 percent of the total in 1962. What Federal agencies account for most of the spending? What is the purpose of the R. & D. they support? How has the relative importance of various agencies in this area shifted over time?

In 1964, well over half the total R. & D. expenditures made by the Federal Government were made by the Department of Defense (table 9) to provide new and improved weapons and techniques to promote the effectiveness of the Armed Forces. The largest expenditures were made by the Air Force; the smallest, by the Army. Relatively little was spent on basic research, about 85 percent having been devoted to development (table 10).

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[20] The 1945 figures come from [37] and are not entirely comparable with those in the tables below. Of course, part of the increase in R. & D. expenditures is undoubtedly due to inflation and shifting definitions of R. & D., but even when these factors are taken into account, it is generally agreed that there still has been a tremendous growth in R. & D. expenditures.

The research that was supported was mainly in the physical and engineering sciences.

The second and third largest spenders on R. & D. in 1964 were the National Aeronautics and Space Administration and the Atomic Energy Commission, both intimately connected with defense and the cold war. Together with the Defense Department, they account for almost 90 percent of the R. & D. expenditures of the Federal Government. Over half the R. & D. carried out by NASA was research rather than development, most of it in the engineering sciences. About one-quarter of the AEC's R. & D. expenditures were for research, mostly in the physical sciences.

In contrast with the big three, the fourth, fifth, and sixth largest spenders are not concerned primarily with national defense and the space race. Practically all of the R. & D. expenditures of the Department of Health, Education, and Welfare, the fourth largest spender, are related to the work of the National Institutes of Health, the research arm of the Public Health Service. The bulk of the research expenditures of HEW were in the medical sciences, and about one-fifth were conducted intramurally in 1964. The fifth largest spender was the National Science Foundation whose general purposes are the encouragement and support of basic research and education in the sciences.

TABLE 8. SOURCES OF R. & D. FUNDS AND PERFORMERS OF R. & D., BY SECTOR, UNITED STATES, 1953–54, 1961–62

Sources of R. & D. funds (sector)	R. & D. performance, by sector				
	Federal Government	Industry	Colleges and universities	Other nonprofit organizations	Total
	1953-54 Transfer of funds (millions)				
Federal Government	$970	$1,430	$280	$60	$2,740
Industry	-----	2,200	20	20	2,240
Colleges and universities	-----	-----	130	-----	130
Other nonprofit organizations	-----	-----	20	20	40
Total	970	3,630	450	100	5,150
	1961-62 Transfer of funds [1] (millions)				
Federal Government	$2,090	$6,310	$1,050	$200	$9,650
Industry	-----	4,560	55	90	4,705
Colleges and universities	-----	-----	230	-----	230
Other nonprofit organizations	-----	-----	65	90	155
Total	2,090	10,870	1,400	380	14,740

[1] Preliminary figures.

SOURCE: *National Science Foundation Reviews of Data on Research and Development*, No. 41 (September 1963).

TABLE 9. FEDERAL EXPENDITURES FOR RESEARCH AND DEVELOPMENT AND R. & D. PLANT, BY AGENCY, FISCAL YEARS 1940–64, IN MILLIONS OF DOLLARS

Department or agency	1940	1948	1956	1960	1964 [1]
Agriculture	29.1	42.4	87.7	131.4	188.3
Commerce	3.3	8.2	20.4	33.1	114.9
Defense	26.4	592.2	2,639.0	5,653.8	7,671.7
Army [2]	3.8	116.4	702.4	1,108.9	1,508.3
Navy [2]	13.9	287.5	635.8	1,300.6	1,742.7
Air Force	8.7	188.3	1,278.9	2,978.0	3,814.7
Advanced research projects agency	-----	-----	-----	226.3	256.8
Departmentwide funds	-----	-----	21.9	40.0	349.3
Health, Education, and Welfare [3]	2.8	22.8	86.2	324.2	811.2
Interior	7.9	31.4	35.7	65.3	123.6
Atomic Energy Commission	-----	107.5	474.0	985.9	1,498.9
Federal Aviation Agency	-----	-----	-----	41.2	92.9
Manhattan Engineer District	-----	-----	-----	-----	-----
National Aeronautics and Space Administration [4]	2.2	37.5	71.1	401.0	4,186.3
National Science Foundation	-----	-----	15.4	58.0	193.0
Office of Scientific Research and Development	-----	.9	-----	-----	-----
Veterans Administration	-----	-----	6.1	18.6	40.1
All other agencies	2.4	11.8	10.4	25.4	58.2

[1] Estimates based on requests in *The Budget, 1964*.

[2] Includes pay and allowances of military personnel support from procurement appropriations beginning in 1954.

[3] Public Health Service and Federal Security Agency prior to 1952.

[4] National Advisory Committee on Aeronautics prior to 1958.

SOURCE: *Federal Funds for Science XII* (National Science Foundation, 1964), table 32. These figures are not comparable with those in tables 7 and 8, but they indicate the breakdown among agencies.

TABLE 10. FEDERAL OBLIGATIONS FOR RESEARCH AND DEVELOPMENT, BY DEPARTMENT, CHARACTER OF WORK, AND FIELD OF SCIENCE, 1964, IN MILLIONS OF DOLLARS[1]

Department	Character of work			Total intramural	Research obligations, by field of science						
	Total research	Basic research	Development		Biological	Medical	Agricultural	Physical	Mathematical	Engineering	Social[2]
Agriculture	175.9	64.5	8.1	124.4	13.7	14.9	75.8	32.6	0.4	14.1	24.4
Commerce	47.1	28.1	21.9	51.7	.1	-----	-----	29.6	.9	10.6	4.6
Defense	1,203.4	207.7	6,416.4	1,851.7	46.0	44.4	.4	480.8	51.3	455.8	2.3
Health, Education, and Welfare	839.3	279.1	3.1	155.0	19.7	716.9	-----	2.9	.1	-----	38.7
Interior	110.6	43.1	14.6	99.9	23.5	.2	1.1	50.0	1.2	31.5	.8
Labor	7.5	1.3	2.8	9.2	-----	-----	-----	-----	-----	.2	7.3
Post Office	.2	-----	10.9	1.3	-----	-----	-----	-----	-----	.2	-----
State	16.9	-----	1.6	5.2	-----	2.1	6.2	-----	-----	.1	8.1
Treasury	.5	.3	1.2	1.5	-----	-----	-----	.5	-----	-----	-----
Atomic Energy Commission	330.4	261.9	864.5	17.3	44.8	19.9	2.0	220.7	7.1	35.9	-----
Federal Aviation Agency	4.3	-----	55.2	22.5	-----	3.1	-----	-----	-----	1.2	-----
Housing and Home Finance Agency	2.3	-----	-----	2.2	-----	-----	-----	-----	-----	-----	2.3
National Aeronautics and Space Administration	2,784.4	677.9	1,887.7	380.4	77.3	1.5	-----	613.0	89.7	1,992.6	.9
National Science Foundation	209.1	209.1	2.0	12.9	39.1	8.5	-----	105.1	16.6	23.2	10.1
Smithsonian	4.8	4.8	-----	4.8	1.6	-----	-----	1.5	-----	-----	1.6
Tennessee Valley Authority	3.0	-----	1.1	4.0	-----	-----	.9	.7	-----	1.4	-----
Veterans Administration	32.7	4.1	.7	32.4	-----	29.7	-----	-----	-----	.3	-----
Arms Control and Disarmament Agency	10.4	-----	2.6	5.7	.2	-----	-----	-----	.6	2.7	3.4

[1] Excludes agencies spending less than $1.5 billion.

[2] Exclude psychology.

SOURCE: *Federal Funds for Science XII* (National Science Foundation, 1964).

Most of the Foundation's expenditures go for research in the physical and biological sciences. The sixth largest spender was the Department of Agriculture, where most of the R. & D. effort, which is coordinated with the research and educational activities of the land-grant colleges, is concerned with the production, utilization, and marketing of farm and forest products. These six departments and agencies accounted for practically all the Federal Government's R. & D. expenditures in 1964.

Table 9 shows the spectacular growth in total expenditures on R. & D. financed by the Federal Government. In 1964 these expenditures were about 200 times what they were in 1940, and 4 times what they were in 1956. Much of this increase has been due to wartime and postwar defense needs. Thus, the Defense Department's share of the total has risen during the period (although not during the last few years), and the AEC's and NASA's shares have also grown substantially. The result has been a tremendous emphasis in the Government R. & D. budget on defense and space technology.

7. Interindustry Differences in R. & D. Expenditures

Which industries spend most on R. & D.? Which spend least? What do R. & D. expenditures in various industries actually go for? How much goes for basic research? applied research? development? How much goes for new products? product improvements? new processes? The National Science Foundation's annual surveys of American industry help to answer many of these basic questions.

At present, R. & D. performance as a percentage of sales is highest in the aircraft, instrument, electrical equipment, and chemical industries (tables 11 and 12), due in considerable part to the fact that these industries carry out a great deal of R. & D. for the Federal Government. In 1963, the Federal Government financed 90 percent of the R. & D. in the aircraft industry, 63 percent in the electrical equipment industry, and 47 percent in the instruments industry. The situation in all industries in 1963 is shown in table 12.[21]

When company-financed R. & D. rather than R. & D. performance is considered, the differences among industries are reduced, but the industries remain in much the same rank order, with instruments, electrical equipment, chemicals, and machinery highest. These industries are closely related to scientific fields and hence the profitability of R. & D. is probably higher than in other industries. (This hypothesis was discussed in sec. 3.)

Table 13 provides a breakdown of the amount spent by industry on basic research, applied research, and development for 1961.[22] Basic research constitutes the largest percentage of R. & D. expenditures in the chemical and petroleum industries, but in no case does it exceed 20 percent of the total. Development is a particularly large percent of the total in the aircraft industry. For all industries combined, about 4 percent of the total was basic research, 18 percent was applied research, and 78 percent development. Of company-financed R. & D. rather than R. & D. performance, about 7 percent of the total, rather than 4, was devoted to basic research.

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[21] 1963 figures are the most up-to-date available from NSF at this writing.

[22] The most up-to-date NSF figures of this sort that I could find pertain to 1961. The results for more recent years are probably much the same. For the NSF definitions of basic research, applied research, and development, see *Research and Development in Industry, 1961*, National Science Foundation, 1964.

TABLE 11. PERFORMANCE OF INDUSTRIAL RESEARCH AND DEVELOPMENT, BY INDUSTRY, 1927–61
PERCENT OF SALES

R. & D. performance	1927	1937	1951	1957	1961[1]
Aircraft and parts	N.A.	N.A.	11.9	22.3	24.2
Instruments	N.A.	N.A.	3.2	5.5	7.3
Electrical equipment	0.54	1.17	3.8	5.5	10.4
Chemicals	.42	1.04	1.6	2.5	4.6
Rubber	.36	.96	.6	1.2	2.2
Machinery	N.A.	.43	.5	2.4	4.4
Stone, clay, and glass	.13	.39	.5	.7	1.8
Motor vehicles	.07	.19	.5	2.36	2.9
Other transportation equipment	.07	.07	.3		
Primary metals and products	.07	.13	N.A.	N.A.	N.A.
Frabricated metal	N.A.	N.A.	.4	.6	1.3
Primary metal	N.A.	N.A.	.2	.4	.8
Petroleum	.09	.44	.6	.8	1.0
Paper	.06	.17	.2	.5	.7
Food	.02	.04	.07	.14	.3
Forest products	.01	.04	.03	N.A.	.5
Leather	.01	.02	.03	N.A.	N.A.
Textiles and apparel	.01	.02	.09	.16	.6

[1] The 1961 figures are not entirely comparable with the earlier ones.
N.A.=Not available.

SOURCE: Brozen, Y., "Trends in Industrial R. & D." *Journal of Business*, July 1960, tables 1-3, and *Research and Development in Industry, 1961* (National Science Foundation, 1964).

TABLE 12. RESEARCH AND DEVELOPMENT PERFORMANCE AND AMOUNT FINANCED BY FEDERAL GOVERNMENT, BY INDUSTRY, 1963, IN MILLIONS OF DOLLARS

Industry	R. &. D performance	Amount financed by Federal Government
Food and kindred products	135	N.A.
Paper and allied products	71	----------
Chemicals and allied products	1,253	264
Industrial chemicals	808	177
Drugs and medicines	215	N.A.
Other chemicals	229	N.A.
Petroleum refining and extraction	315	20
Rubber products	146	39
Stone, clay, and glass products	122	N.A.
Primary metals	191	12
Primary ferrous products	109	2
Nonferrous and other metal products	82	10
Fabricated metal products	162	29
Machinery	977	264
Electrical equipment and communication	2,483	1,562
Communication equipment and electronic components	1,336	871
Other electronic equipment	1,147	691
Motor vehicles and other transportation equipment	1,103	289
Aircraft and missiles	4,835	4,371
Professional and scientific instruments	497	232
Scientific and mechanical measuring instruments	241	143
Optical, surgical, photographic, and other instruments	257	89
Textiles	34	2

N.A.=Not available.

SOURCE: "Research and Development in American Industry, 1963," *Reviews of Data on Science Resources* (National Science Foundation, December 1964).

The McGraw-Hill survey of business plans for new plant and equipment provides further information regarding the character of R. & D. being carried out by industry. In all manufacturing industries combined, about 47 percent of the firms reported in 1961 that their main purpose was to develop new products, 40 percent reported it was to improve existing products, and 13 percent reported it was to develop new processes. Development of new products seemed to be particularly important in the electrical equipment, chemical, and fabricated metal industries. Improvement of existing products seemed to be particularly important in the paper, machinery and metalworking, steel, and textile industries. Development of new processes was particularly important in the petroleum industry.[23]

Finally, table 14 shows that a considerable amount of the applied research and development performed in one industry is directed at products in another industry. In large part this is because firms classified in one industry are often in others

TABLE 13. PERCENT DISTRIBUTION OF FUNDS FOR THE PERFORMANCE OF BASIC RESEARCH, APPLIED RESEARCH, AND DEVELOPMENT, BY INDUSTRY, 1961

Industry	Basic research	Applied research	Development	Total
Food and kindred products	8	N.A.	N.A.	100
Chemicals and allied products	11	37	52	100
Industrial chemicals	12	38	50	100
Drugs and medicines	17	53	31	100
Other chemicals	5	19	76	100
Petroleum refining and extraction	16	42	42	100
Rubber products	7	20	73	100
Stone, clay, and glass products	5	36	58	100
Primary metals	6	N.A.	N.A.	100
Primary ferrous products	8	N.A.	N.A.	100
Nonferrous and other metal products	4	45	51	100
Fabricated metal products	2	30	69	100
Machinery	3	14	83	100
Electrical equipment and communication	3	13	84	100
Communication equipment and electronic components	5	13	82	100
Other electrical equipment	2	13	86	100
Motor vehicles and other transportation equipment	1	N.A.	N.A.	100
Aircraft and missiles	1	10	89	100
Professional and scientific instruments	3	N.A.	75	100
Scientific and mechanical measuring instruments	2	16	82	100
Optical, surgical, photographic, and other instruments	N.A.	N.A.	N.A.	100

N.A.=Not available.

SOURCE: *Research and Development in Industry, 1961* (National Science Foundation, 1964).

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[23] These data are several years old, but it seems doubtful that there has been much of a change since 1961.

as well. For example, many large petroleum refiners are also chemical producers. An important moral of table 14 is that one should not assume that all, or almost all, the R. & D. performed in an industry is directed at that industry's own products.

TABLE 14. FUNDS FOR APPLIED RESEARCH AND DEVELOPMENT PERFORMANCE, BY INDUSTRY AND PRODUCT FIELD, SELECTED INDUSTRIES, 1961, IN MILLIONS OF DOLLARS

Product field	Chemicals [1]	Petroleum	Primary metals	Fabricated metals	Machinery	Electrical equipment [2]	Motor vehicles [3]	Aircraft [4]	Instruments
Aircraft	(5)	(5)	2	1	22	184	53	725	19
Atomic energy	80	(5)	4	27	12	301	12	108	1
Chemicals	506	71	10	(5)	(5)	13	(5)	(5)	15
Drugs	177	---	---	---	(5)	---	---	(5)	(5)
Electrical equipment	(5)	(5)	2	3	(5)	172	(5)	(5)	(5)
Communication equipment	(5)	(5)	2	2	191	1,218	58	562	76
Fabricated metals	7	---	12	30	15	16	16	6	6
Food	19	---	(5)	1	(5)	(5)	---	---	(5)
Missiles	(5)	---	5	2	45	179	78	2,092	28
Machinery	(5)	(5)	(5)	(5)	502	(5)	(5)	(5)	(5)
Motor vehicles	(5)	(5)	4	(5)	25	3	462	24	(5)
Petroleum	4	163	(5)	(5)	1	---	1	---	(5)
Primary metals	(5)	(5)	89	2	4	6	6	(5)	(5)
Instruments	2	8	(5)	4	6	38	2	12	131
Rubber	8	(5)	1	1	1	1	4	(5)	1
Stone, clay and glass	2	(5)	1	2	2	4	(5)	2	2
Other	(5)	(5)	(5)	(5)	29	68	19	262	22
Total	950	248	150	117	870	2,326	793	3,907	372

[1] Includes drugs.
[2] Includes communication.
[3] Includes other transportation equipment.
[4] Includes missiles.
[5] Not separately available but included in total.

SOURCE: *Research and Development in Industry, 1961* (National Science Foundation, 1964).

8. Industrial Decisionmaking Regarding R. & D. Expenditures

While it has been possible to present the salient facts on the size and distribution of industrial R. & D. expenditures, it is more difficult to provide insight concerning the way in which firms make decisions in this area. This section summarizes the results of some of the few studies that have been carried out; more work is required.

With regard to total R. & D. expenditures, Mansfield [47a] and Seeber [78] found that in the short run firms tend to maintain a fairly constant ratio between R. & D. expenditures and sales, some executives using such ratios as rules of thumb. Over the longer run, firms obviously change this desired ratio, particularly in response to changes in the prospective profitability of research and development. Although this profitability is very difficult to measure and firms can make only crude attempts to do so, Mansfield [48] provides considerable evidence that estimates of this variable play an important role in determining the size of R. & D. expenditures.

The size of a firm's R. & D. budget is also influenced by a kind of "bandwagon effect." Research by one segment of an industry tends to encourage research in other segments of the same and other industries, both because it makes additional research profitable and because firms, like people, tend to follow the leader. Still another factor is the emphasis firms seem to place on the stability of their R. & D. programs. According to interview studies by the National Science Foundation [60], expansions of their program are avoided if they may soon have to be cut back. Moreover, because of the costs involved in rapid expansion, firms try to build up to a desired level over a period of years. According to Mansfield's econometric studies [48], a firm's speed of adjustment toward the desired level depends on the extent to which the desired level differs from the previous year's level, and on the percent of its profits that were spent on R. & D. in the previous year.

Assuming a firm somehow sets its total expenditures on R. & D., how does it decide which projects to spend its money on? Perhaps the best way to answer this question is to describe briefly the procedure that is used in the central research laboratory of one of the Nation's largest firms, a major equipment producer. This procedure is used for applied research and development, but not basic research. Considered will be only the projects proposed by the operating divisions, since the procedure for the others, excluding basic research, is much the same.

In the summer of 1962, the laboratory asked its divisions for proposals for 1963. For each proposal, a division was requested to estimate (1) the probability of commercial success of the project (if technically successful); (2) the extra profit to the firm if the project were commercially successful; and (3) the investment required to put the research results into practice. These proposals were then sent to the managers of the relevant laboratory departments who made preliminary estimates of the cost of doing the R. & D. and the corresponding chance of technical success. On the basis of the information provided by the division and the department manager, the laboratory's project evaluation group, a small group of project analysts that report to laboratory management, computed a "figure of merit" for each proposal and rated it "A," "B," or "C." Then the rated requests were returned to department managers who then formulated their respective R. & D. programs. "A" proposals were recommended to be given top priority and "C" proposals to be avoided. The department managers then formulated a number of research projects, each aimed at satisfying one or more of the proposals. The laboratory management then evaluated each proposal, decided whether to accept or reject it, and suggested a level of expenditures on each accepted project. Finally, the resulting list of projects went to corporate management for approval.

According to Mansfield and Brandenburg [53], four factors seem to be particularly important in explaining the decisions that were made: First, to the extent possible, the level of spending on a particular project tended to be set at the point where further increases in the probability of success would no longer be worth their cost. Second, safe projects seemed to be preferred over risky ones. Third, some projects were justified more on the basis of scientific interest than expected profit. Fourth, projects differed considerably in the amount of pressure applied by operating executives to have them carried out and in the amount of salesmanship used by the scientists themselves.[24]

9. Profitability and Riskiness of Industrial Research and Development

What are the characteristics of industrial R. & D.? Two of the most important characteristics of any economic activity are its profitability and riskiness, and R. & D. is no exception. For some years, the McGraw-Hill Economics Department gathered data from firms regarding the expected profitability of their R. & D. programs. Table 15 shows for each industry in 1958 and 1961 the distribution of firms classified by their expected payout period for research and development. Although this is a very crude measure of profitability, it is all that is available on a widespread basis. According to McGraw-Hill, the 1958 expected returns on R. & D. were

> significantly better than the typical returns or payoff on investment in new plant and equipment, . . . [which helps to] make it clear why many companies with a given amount of capital to reinvest found it profitable to increase the proportion going to research and development.[25]

In more recent years, there is considerable evidence that firms have been scrutinizing their R. & D. expenditures more carefully, and that expected returns have sometimes been adjusted downward.

TABLE 15. EXPECTED AVERAGE PAYOUT PERIODS FROM R. & D. EXPENDITURES, 1958 AND 1961, PERCENT OF COMPANIES ANSWERING

Industry	1958			1961		
	Less than 3 years	3 to 5 years	6 years and over	3 years or less	4 to 5 years	6 years and over
Iron and steel	50	50	0	38	50	12
Nonferrous metals	42	42	16	64	18	18
Machinery	49	45	6	51	39	10
Electrical machinery	23	69	8	61	32	7
Autos, trucks, and parts	40	60	0	54	40	6
Transportation equipment (aircraft, ships, railroad equipment)	24	65	11	43	44	13
Fabricated metals and instruments	24	71	5	77	14	9
Chemicals	15	56	29	33	41	26
Paper and pulp	25	69	6	50	32	18
Rubber	50	17	33	38	38	24
Stone, clay, and glass	44	50	6	38	46	16
Petroleum and coal products	12	63	25	17	33	50
Food and beverages	37	54	9	54	43	3
Textiles	65	29	6	76	24	0
Miscellaneous manufacturing	66	31	3	71	25	4
All manufacturing	39	52	9	55	34	11

SOURCE: McGraw-Hill, *Business Plans for Expenditures on Plant and Equipment*, annual.

For a small group of firms and industries, Mansfield [45] has made some very tentative and experimental estimates of the marginal rate of return from R. & D. expenditures, i.e., the rate of return from an extra dollar spent for research and development. Specifically, estimates were made for 10 major chemical and petroleum firms and 10 manufacturing industries, the results pertaining to 1960. Judging from the data for individual firms, the marginal rate of return was very high in petroleum; in chemicals, it was high if technological change was capital-embodied but low if it was organizational. Turning to the industry data, the marginal rate of return seems to be relatively high, 15 percent or more, in the food, apparel, and furniture industries. Needless to say, these results are extremely rough and should be taken with a generous helping of salt.

Turning from profitability, one of the most obvious and important characteristics of inventive activity is its riskiness. Chance plays a crucial role, and a long string of failures is often required before any sort of success is achieved. For example, a recent survey of 120 large companies doing a substantial amount of R. & D. indicates that in half of these firms at least 60 percent of the R. & D. projects never resulted in a commercially used product or process. (The smallest failure rate for any of these firms was 50 percent.) Moreover, even when a project resulted in a product or process that was used commercially, the profitability of its use was likely to be quite unpredictable.[26]

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[24] Needless to say, this section described only a few aspects of the relevant decisionmaking process. For further discussion, see the references cited in [53].

[25] Keezer, Greenwald, and Ulin [37], p. 366.

A study carried out by the Rand Corp. [54] goes further to describe the extent of the difficulties in predicting the results of development projects. First, the study showed that there were substantial errors in the estimates made prior to development of the costs of producing various types of military hardware. When adjusted for anticipated changes in factor prices and production lot sizes, the average ratio of the actual to estimated cost was 1.7 (fighters), 3 (bombers), 1.2 (cargoes and tankers), and 5.2 (missiles). Thus, these estimates were off, on the average, by as much as 400 percent—and almost always they understated the true subsequent costs.

Second, the extent to which costs were understated was directly related to the extent of the technical advance. In cases where a "large" technical advance was required, the average ratio was 4.2; in cases where a "small" technical advance was required, the average ratio was 1.3. Moreover, when corrected for bias, there was much more variation in the ratio where the required technical advance was large than where it was small. Thus, as would be expected, the uncertainty was greater for more ambitious projects than less ambitious ones.

Third, there were very substantial errors in the estimated length of time it would take to complete a project. For 10 weapons systems, the average error was 2 years, and the maximum, 5 years. The average ratio of the actual to the expected length of time was 1.5, indicating once again that estimates tend to be overly optimistic. The results suggest too that the estimates are more accurate when "small" rather than "large" technical advances must be made.

Fourth, given the extent of the technical advance that had to be made, estimates of development and production costs and required development time became more accurate as the project ran its course [41]. For example, at the early stages of projects requiring advances of "medium" difficulty, the average ratio of the actual to expected cost was 2.15 and the standard deviation was 0.57. At the middle stages of such projects, the average ratio was 1.32 and the standard deviation, 0.39. At the late stages of such projects, the average ratio was 1.06 and the standard deviation, 0.18.

The findings of the Rand study pertain entirely to military R. & D. Although the errors in estimation in the civilian economy are likely to be smaller than those presented above, they too are probably quite large in cases where "large" technical advances are attempted. See Mansfield and Brandenburg [53].)

10. Productivity of R. & D. Expenditures

Another important characteristic of industrial research and development is its "productivity", i.e., output of significant, though not necessarily profitable, inventions.[27] On the basis of the crude measurements that can be made, does it seem that a firm's output of significant inventions is closely related to the amount it spends on R. & D.? Is there any evidence that the productivity of R. & D. activities increases with the amount spent on R. & D.? Is there any evidence that productivity is greater in large firms than small ones?

To help answer these questions, Mansfield [48] studied the chemical, petroleum, and steel industries, using Langenhagen's, Schmookler's, and his own data regarding the weighted number of significant inventions carried out by about 10 large firms in each industry. Calculations based on these crude data suggest the following three conclusions: First, holding size of firm constant, the number of a firm's significant inventions seems to be highly correlated with the size of its R. & D. expenditures. Thus, although the output from an individual R. & D. project is obviously very uncertain, a close relationship seems to exist over the long run between the amount spent on R. & D. and the total number of important inventions produced.

Second, the evidence from this cross-sectional analysis suggests that increases in R. & D. expenditures in chemicals, in the relevant range and holding size of firm constant, result in more than proportional increases in inventive output. But in petroleum and steel, there is no real indication of either economies or diseconomies of scale within the relevant range. Thus, except for chemicals, the results do not indicate any marked advantage of very large scale over medium-size and large research activities. Third, when expenditures on R. & D. are held constant, increases in size of firm seem to be associated in most industries with decreases in inventive output. Thus, the evidence suggests that the productivity of an R. & D. effort of given scale is lower in the largest firms than in the medium-size and large ones.[28]

11. Is There an Underinvestment in Research and Development?

Why is it necessary for the Federal Government to support considerable nonmilitary research? Cannot free enterprise be relied upon to allocate resources efficiently in the area of R. & D.? Will not the right sort of R. & D. be carried out? There are at least two major reasons for believing that a free enterprise economy will generate less R. & D. than is socially desirable, and that the deficiency will be particularly acute in the area of basic and more risky types of research.

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[26] See R. Nelson, "The Economics of Invention: A Survey of the Literature," *Journal of Business*, 1959.

[27] An invention may be of great importance to the industry as a whole but not particularly profitable to the firm responsible for the invention.

[28] Note that these results are based on only a small amount of very rough data which pertain to only three industries. Unfortunately, they seem to be all that are currently available.

First, considerable discrepancies clearly exist between the private and social benefits to be obtained from research. The results of R. & D. often are of little direct value to the sponsoring firm but of great value to other firms, and the results of R. & D. often cannot be quickly patented. This problem of "external economies" is particularly acute in the case of basic research [63]. Second, it is often argued that many firms are risk averters and risk cannot be shifted completely and perfectly; therefore, investment in risky activities tends to fall short of the social optimum—the point where expected returns equal the market rate of return, regardless of the variance. Arrow [3] and [4] and Nelson [63] present arguments to this effect.

Both these factors result in too little being spent on R. & D.; thus, for an optimal allocation of resources, the Government or some other agency not motivated by profit apparently should finance additional research and development. Formally, it should push its contribution to the point where marginal social benefit equals the marginal social benefit from the relevant resources in alternative uses, obviously a very difficult thing to measure. Griliches' study [28] is probably the most interesting attempt to measure the social rate of return from R. & D.; it concludes that the return from the investment in agricultural research has been very high.

Many economists believe that despite the considerable expenditures made by the Federal Government, there is still an underinvestment in R. & D. According to the Council of Economic Advisers [13],

> in a number of industries the amount of organized private research undertaken is insignificant, and the technology of many of these low-research industries has notably failed to keep pace with advances elsewhere in the economy.[29]

Freeman, Poignant, and Svennilson, in their OECD report [24], conclude that,

> in spite of the great increase in research and development activity, there are good reasons for believing that in many cases this activity is still below the level desirable for efficient and sustained economic growth.[30]

Many economists also believe that there is a malallocation of R. & D. expenditures. According to Ross [68], too much of our scarce engineering and scientific talent tends to be used in defense and space work. According to Nelson [62],

> . . . aside from the fields of defense and space, peacetime atomic energy, and perhaps public health, it is likely that we are relying too much on private incentives as stimulated by the market to generate R. & D. relevant to the public sector. . . . [Also,] aside from the fields of defense and space, there probably is too little research and experimentation aimed at exploring radically new techniques and ways of meeting needs. . . . [S]urely we can do better than to rely so heavily on "spillover" from defense and space to open up the really new possibilities in materials, energy sources, etc.[31]

Those who believe that there is an underinvestment in R. & D. and/or that R. & D. expenditures are malallocated generally favor public policies to support additional R. & D. in the areas where they believe there is a deficiency, through Government contracts and tax credits. See Nelson [62] and Freeman, Poignant, and Svennilson [24]. In addition, numerous proposals have been made to increase the efficiency of military and space R. & D. See Klein [41] and Peck and Scherer [65]. Finally, all these economists recognize that there is precious little evidence to support or deny their beliefs. Thus, much more "research on research" is badly needed.

12. Market Structure and Technological Change

Economists have also been concerned with another important question: Will an industry dominated by a few large firms be more progressive than one composed of a larger number of smaller firms? Without pretending that the profession has reached anything approaching an answer, it is nonetheless useful to summarize briefly the evidence to date.

In discussing this question several related issues should be distinguished. First, what is the effect of an industry's market structure on the amount it spends on R. & D.? Although the results obtained by Hamberg [31], Mansfield [48], and Scherer [73] are extremely tentative, they do not suggest that total R. & D. expenditures in most industries would decrease considerably if the largest firms were replaced by several smaller ones. However, if concentration were reduced greatly, one would expect a considerable decrease, since firm size often must exceed a certain minimum for R. & D. to be profitable.

Second, what is the effect of an industry's market structure on the productivity of a specified amount spent on R. & D.? To the extent that the tentative results described in section 10 are dependable, they indicate that the R. & D. expenditures carried out by the largest firms are generally no more productive per dollar of R. & D. expenditures than those carried out by somewhat smaller firms. Third, what is the effect of an industry's market structure on the rapidity with which new processes and products, developed by both the industry and others, are introduced commercially? The answer seems to depend very heavily on the types of innovations that happen to occur. If they require very large amounts of capital, increased concentration appears to lead to a more rapid introduction; if they require small amounts of capital, this may not be the case [48a].

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[29] Council of Economic Advisers [13], p. 105.

[30] Freeman, Poignant, and Svennilson [24], p. 42.

[31] Nelson [62], p. 17.

Finally, what is the effect of an industry's market structure on how rapidly innovations, once introduced, spread throughout an industry? The very small amount of evidence bearing on this question seems to suggest that greater concentration may be associated with a slower rate of diffusion. However, the observed relationship is extremely weak and could well be due to chance.

13. Summary and Conclusion

The principal points of part III can be summarized as follows: First, the rate of technological change in an industry depends to a large extent on the amount of resources devoted by members of the industry and by the Government to the improvement of the industry's technology. The amount of resources devoted by the Government depends on how closely the industry is related to the defense, medical, and other social needs for which Government assumes primary responsibility; on the extent of the external economies generated by the relevant R. & D.; and on various political factors. The amount of resources devoted by private industry depends heavily on the expected profitability of this kind of investment.

Second, total R. & D. expenditures in the United States have increased spectacularly during the last several decades, with much of the R. & D. performed by industry and universities being financed by the Federal Government. At present, three agencies, DOD, NASA, and AEC, account for abount 90 percent of the R. & D. expenditures of the Federal Government. Their primary purpose is the development and improvement of weapons systems, the advancement of the space program, and the development of atomic energy. The bulk of their expenditures is for development, not research, and most of their research expenditures are in the physical and engineering sciences.

Third, although the independent inventor is still important, the R. & D. departments of industrial concerns are becoming more and more significant as a source of inventions. R. & D. is spread very unevenly among industries, being highest, as a percent of sales, in the aircraft, instruments, electrical equipment, and chemical industries. When company-financed R. & D. rather than R. & D. performance is considered, the differences among industries are reduced; however, the industries remain in much the same rank order, with instruments, electrical equipment, chemicals, and machinery highest.

Fourth, it is extremely difficult for a firm to evaluate the returns from its investment in research and development, a difficulty reflected in the process of industrial decisionmaking regarding R. & D. In the late fifties and early sixties, the expected returns from R. & D. seem to have been higher than from investment in plant and equipment. More recently, firms seem to be scrutinizing their R. & D. expenditures more carefully and are somewhat less optimistic about returns. With regard to the riskiness of industrial R. & D., studies indicate that more than 50 percent of a firm's R. & D. projects generally fail and that cost and completion date estimates of projects generally are very poor.

Fifth, a number of economists believe that there is an underinvestment in R. & D. because private returns do not adequately reflect social returns. Others charge that there is a malallocation of R. & D. expenditures. The commonly recommended remedies are Government grants and tax credits to support additional R. & D. in deficient areas. Numerous proposals have also been made to increase the efficiency of military and space R. & D. Unfortunately, there is far less evidence to guide public policies in these areas than would seem desirable.

Finally, economists have been concerned for many years with the relationship between an industry's market structure and its technical progressiveness. Recently, empirical studies that apply modern econometric techniques have been emphasized. The results, which are extremely tentative, provide little evidence that industrial giants are needed in all, or even most, industries to insure rapid technological change. However, this does not mean that very large firms are not needed in some industries. Again, unfortunately, there is far less evidence than seems desirable.

Part IV: THE DIFFUSION OF INNOVATIONS

1. Introduction

Technological change has been defined as a shift in the production function, i.e., a new relationship between input and output. This new relationship is potential, not actual, since firms are free to adopt new techniques as slowly or as rapidly as they please, subject of course to the constraints imposed by the marketplace. Consequently, the rate of diffusion of an innovation is of great importance because it determines how rapidly productivity increases in response to the new technique. How rapidly do innovations spread? What determines their rate of diffusion? What sorts of firms tend to be the technical leaders and followers? Is diffusion more rapid now than in the past?

Section 2 discusses the importance of innovation, as well as the timing of important innovations. Section 3 presents data regarding the rate of diffusion of innovations in various industries. Section 4 discusses the factors determining how rapidly an innovation spreads. Sections 5 and 6 are concerned with the characteristics of the firms that are relatively quick or slow to innovate. Section 7 discusses the determinants of the intrafirm rate of diffusion of an innovation. Section 8 examines the available evidence to see whether the diffusion process seems to be more rapid now than in earlier years. Section 9 discusses the use of performance-based Federal procurement as a spur to innovation. Section 10 summarizes the findings.

2. Innovation: Importance and Timing

An invention applied for the first time becomes an innovation. The distinction is important because an invention has little or no economic significance until it is applied. Innovation is a key stage in the process of technical progress. The innovator—the firm that first applies the invention—must be willing to risk introducing a new and untried process, good, or service. By testing the actual performance of the invention, the innovator plays a vital social role.

The lag between invention and innovation varies substantially, since some inventions require changes in tastes, technology, and factor prices before they can profitably be utilized, whereas others do not. But beyond this, the only data we have about the distribution of this lag are provided by Enos [21] who estimated the time interval between invention and innovation for 11 important petroleum refining processes and 35 important products and processes in a variety of other industries. Needless to say, these data are extremely rough, since the sample is not random and such concepts as "invention" and "innovation" are not easy to pinpoint and date. Nonetheless, his results provide some feel for the distribution of the lag.

Table 16 shows that the lag averaged about 13 years in the petroleum industry and about 14 years in others. Its standard deviation is about 5 years in the petroleum industry and 16 years in the others. Enos [21] concludes that:

> Mechanical innovations appear to require the shortest time interval with chemical and pharmaceutical innovations next. Electronic innovations took the most time. The interval appears shorter when the inventor himself attempts to innovate than when he is content merely to reveal the general concept.[32]

TABLE 16. ESTIMATED NUMBER OF YEARS BETWEEN INVENTION AND INNOVATION, 46 INVENTIONS, SELECTED INDUSTRIES

Invention [1]	Interval	Invention	Interval
Distillation of hydrocarbons with heat and pressure (Burton)	24	Spinning jenny	5
Distillation of gas oil with heat and pressure (Burton)	3	Spinning machine (water frame)	6
Continuous cracking (Holmes-Manley)	11	Spinning mule	4
Continuous cracking (Dubbs)	13	Steam engine	11
"Clean circulation" (Dubbs)	3	Ballpoint pen	6
Tube-and-tank process	13	DDT	3
Cross process	5	Electric precipitation	25
Houdry catalytic cracking	9	Freon refrigerants	1
Fluid catalytic cracking	13	Gyrocompass	56
Gas lift for catalyst pellets	13	Hardening of fats	8
Catalytic cracking (moving bed)	8	Jet engine	14
Safety razor	9	Turbojet engine	10
Fluorescent lamp	79	Longplaying record	3
Television	22	Magnetic recording	5
Wireless telegraph	8	Plexiglass, lucite	3
Wireless telephone	8	Cotton picker	53
Triode vacuum tube	7	Nylon	11
Radio (oscillator)	8	Crease-resistant fabrics	14
		Power steering	6
		Radar	13
		Self-winding watch	6
		Shell moulding	3
		Streptomycin	5
		Terylene, dacron	12
		Titanium reduction	7
		Xerography	13
		Zipper	27

[1] The first 11 inventions in this column occurred in petroleum refining. For the estimated dates of invention and innovation and the identity of the inventors and innovators, see Enos [21].

SOURCE: Enos [21], pp. 307–308.

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[32] Enos [21], p. 309.

Mansfield [49] has studied the timing of about 175 significant innovations in the iron and steel, petroleum refining, and bituminous coal industries. According to his results, process innovations were most likely to be introduced during periods when these industries were operating at about 75 percent of capacity. Contrary to the opinion of many economists, there was no tendency for innovations to cluster at the peak or trough of the business cycle. Apparently process innovation at the trough was discouraged by the meagerness of profits and the bleakness of future prospects; at the peak, it was discouraged by the lack of unutilized capacity. For product innovations, there was no evidence that the rate of innovation varied significantly over the business cycle.

3. Rates of Diffusion

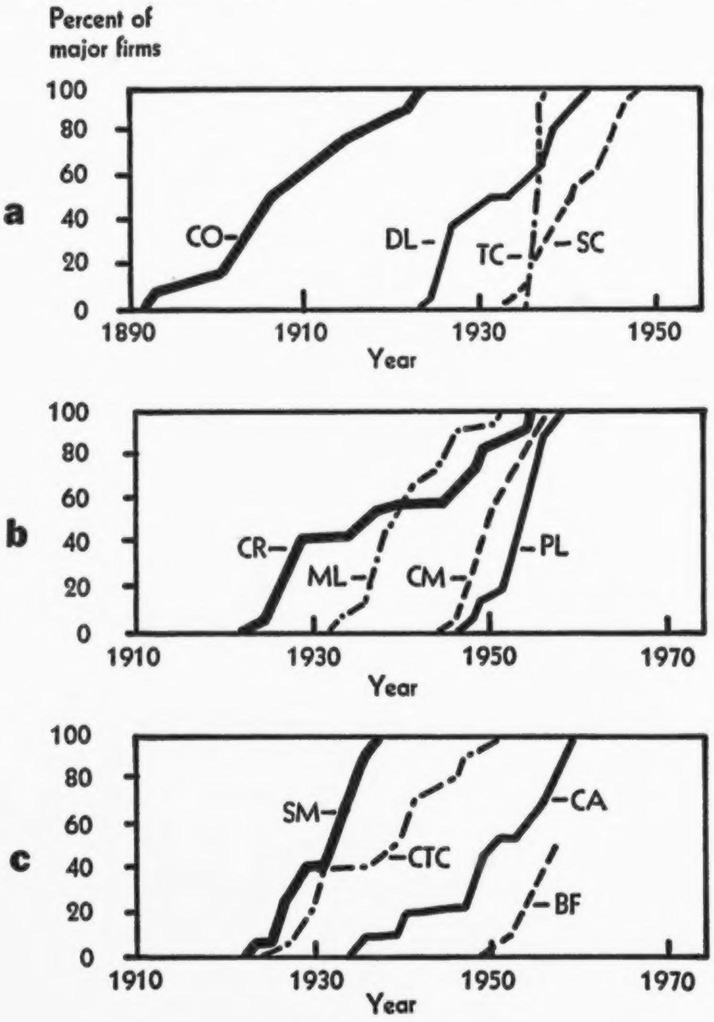
Once an innovation has been introduced by one firm, how rapidly does it spread? One of the earliest noteworthy studies of this question was made by Jerome [33] in 1934. His findings, based on data for 23 machines for periods ranging from 11 to 39 years, indicate

> . . . the following estimates of the typical duration of periods in their life histories: Commercial trial, 3 to 11 years; rapid increase in use, 4 to 11 years; slackened increase (with a customary annual gain of less than 10 percent), 3 to 6 years; decline of undefined length. Processes and types of equipment suffer declines for long periods before they pass completely out of use. They linger on in small plants and for special uses long after they have been replaced by new processes or equipment in the major part of the industry.[33]

In 1961, Mansfield [50] studied how rapidly the use of 12 innovations spread from enterprise to enterprise in 4 industries—bituminous coal, iron and steel, brewing, and railroads. The innovations are the shuttle car, trackless mobile loader, and continuous mining machine (bituminous coal); the byproduct coke oven, continuous wide strip mill, and continuous annealing line for tinplate (iron and steel); the pallet-loading machine, tin container, and high-speed bottle filler (brewing); and the diesel locomotive, centralized traffic control, and car retarders (railroads).

Figure 6 shows the percentage of major firms that had introduced each of these innovations at various points in time. To avoid misunderstanding, note three things regarding these data: First, because of difficulties in obtaining information concerning smaller firms and because in some cases they could not in any event have used the innovations, only firms exceeding a certain size are included. Second, the percentage of firms that introduced an innovation, regardless of the scale on which they did so, is given. Third, in a given industry most of the firms included in the case of one innovation were also included for the others. Thus the data for each innovation are quite comparable in this regard.

FIGURE 6. *Growth in the Percentage of Major Firms That Introduced 12 Innovations, Bituminous Coal, Iron and Steel, Brewing, and Railroad Industries, 1890–1958*



Source: Mansfield [50].

a. Byproduct coke oven (CO), diesel locomotive (DL), tin container (TC), and shuttle car (SC).

b. Car retarder (CR), trackless mobile loader (ML), continuous mining machine (CM), and pallet-loading machine (PL).

c. Continuous wide-strip mill (SM), centralized traffic control (CTC), continuous annealing (CR), and high-speed bottle filler (BF).

Two conclusions emerge from figure 6. First, the diffusion of a new technique is generally a slow process. From the date of the first successful commercial application, it took 20 years or more for all the major firms to install centralized traffic control, car retarders, byproduct coke ovens, and continuous annealing. Only in the case of the pallet-loading machine, tin container, and continuous mining machine did it take 10 years or less for their installation by all the major firms.

Second, the rate of imitation varies widely.

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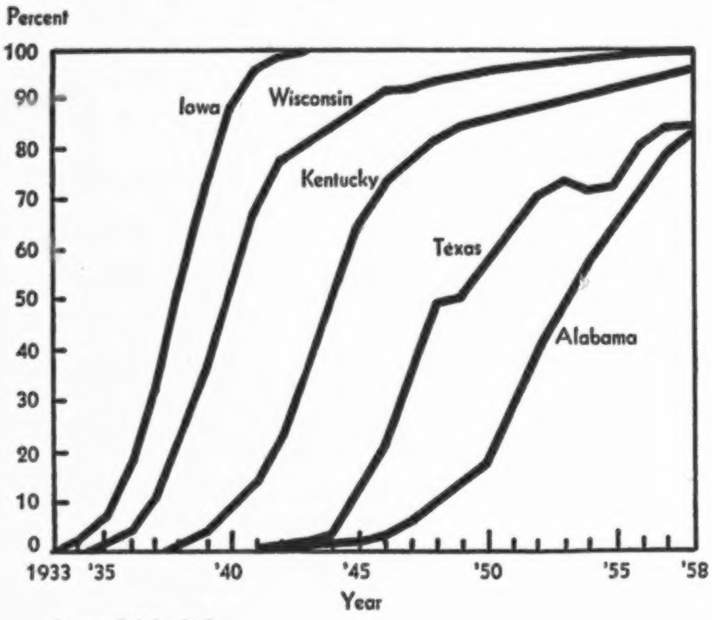
[33] Jerome [33], pp. 20–21.

Sometimes it took decades for firms to adopt a new technique, but in other cases the innovator was imitated very quickly. For example, 15 years elapsed before half the major pig iron producers used the byproduct coke oven, but only 3 years elapsed before half the major coal producers used the continuous mining machine. The number of years elapsing before half the firms introduced an innovation varied from 0.9 to 15.

Interesting studies of the diffusion of agricultural and pharmaceutical innovations have been carried out by Griliches [29], Ryan and Gross [70], and Coleman, Katz, and Menzel [12]. Griliches' work is primarily concerned with differences among regions in the rate of diffusion of hybrid corn. Although serious research on hybrid corn was begun early in the century, the first application of the research results on a substantial commercial scale did not occur until the thirties. As shown in figure 7, some regions began to use hybrid corn earlier than others; and once they had begun, some made the transition to full (or almost full) adoption more rapidly than others. For example, the time interval from 20 to 80 percent of full adoption was 8 years in Alabama but only 3 in Iowa.

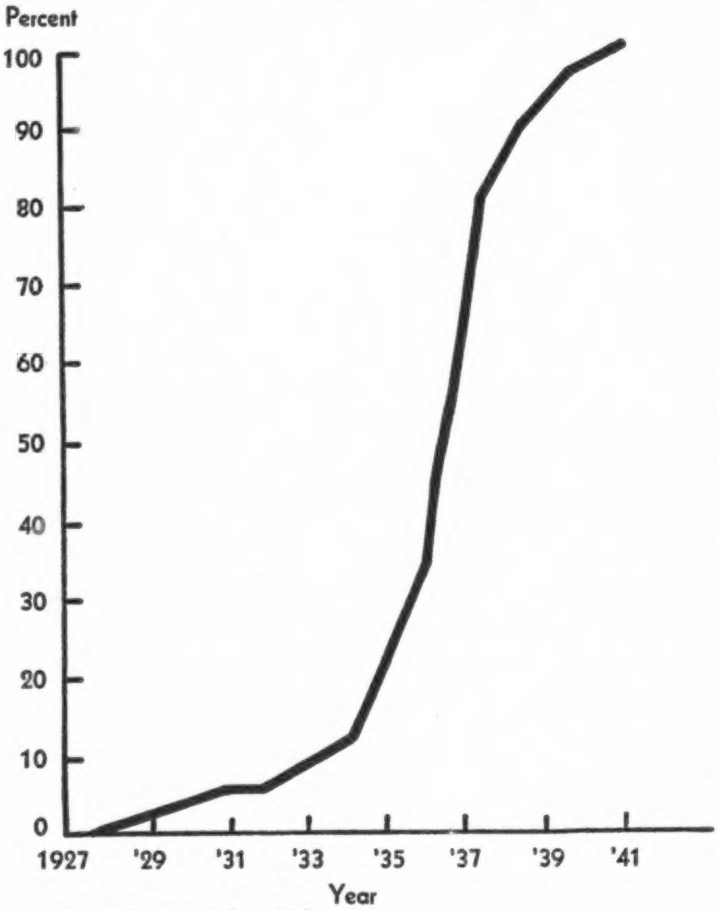
FIGURE 7. *Percentage of All Corn Acreage Planted to Hybrid Seed*



Source: Griliches [29].

Ryan and Gross [70] also investigated the diffusion of hybrid corn, but confined their attention to about 250 farms in two small Iowa communities, Grand Junction and Scranton. Their major findings were: First, the growth in the percentage of users followed an S-shaped curve, as shown in figure 8. Second, three stages were recognized in the adoption process: Awareness (first hearing about the new idea), trial (first use), and adoption (100 percent use). The period from awareness to complete adoption averaged about 9 years for the respondents, with about 5.5 years elapsing from awareness to trial, and about 3.5 years from trial to 100 percent use. Coleman, Katz, and Menzel [12] analyzed the diffusion of a new antibiotic, referred to as "gammanym" (a pseudonym) that appeared in late 1953. The data, which came from four cities in Illinois in 1954, showed the rate at which physicians adopted gammanym, as evidenced by their record of prescriptions written.

FIGURE 8. *Percentage of Farms in Iowa Community Accepting Hybrid Corn*



Source: Ryan and Gross [70].

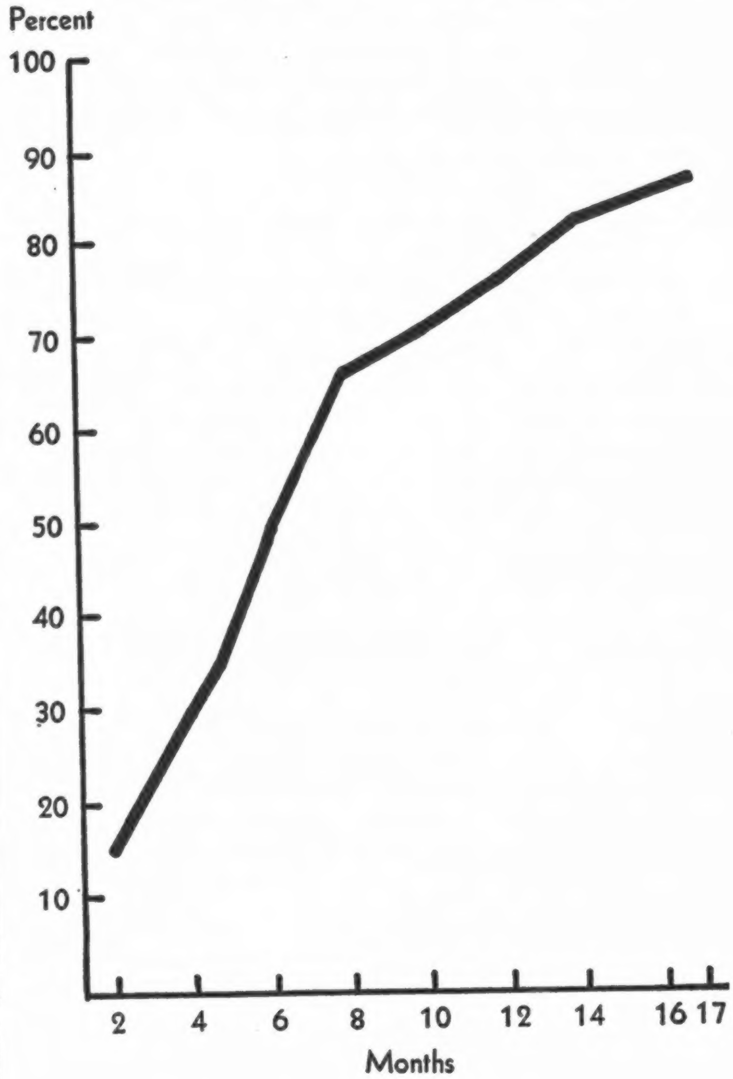
The results in figure 9 indicate that it took about a year for the percentage of users to rise from 20 to 80. The detailed data obtained by Coleman, Katz, and Menzel are useful in analyzing in depth the patterns of influence and the channels through which an innovation spreads.

4. Determinants of the Rate of Diffusion

Before taking up the question of what determines an innovation's rate of diffusion, we should consider the determinants of the ultimate, or equilibrium, level of use of the innovation. For a new process used to make an existing product good or provide an existing service, the equilibrium level of use depends on the extent of its economic advantages over the inputs it is to replace and on the sensitivity of the demand for the product it produces to any price decline or quality increase induced by the invention. For a new final good, the equilibrium level of use depends on how much consumers are willing to purchase at the price at which it can be produced and marketed profitably.

Four factors seem to be most important in determining how rapidly the innovation's level of utilization approaches this ultimate, or equilibrium, level. First, the extent of the economic advantage of the innovation over older methods or products seems to be an extremely important determinant of the rate of diffusion. Mansfield [50] has provided considerable evidence that more profitable innovations spread more rapidly than less profitable ones. Griliches [29] has shown that hybrid corn spread more rapidly in areas where it was more profitable than in areas where it was less so.

Figure 9. *Percentage of Doctors Accepting Gammanyn in a 16-Month Period, Selected Communities*



Source: Coleman, Katz, and Menzel [12].

Second, the extent of the uncertainty associated with using the innovation when it first appears is another important variable. If potential users are very uncertain of the innovation's performance, the invention tends to spread less rapidly than if they are relatively sure of its performance. Thus, new ideas that are relatively simple to understand seem to be accepted more rapidly than more complicated ones. Also, ideas which can easily be verified, which have readily identifiable results, and which are consistent with existing ideas and beliefs, seem to spread more rapidly than others.

Third, there is the extent of the commitment required to try out the innovation. Mansfield [50] has shown that the rate of diffusion of an industrial innovation is inversely related to the size of the investment required to use the innovation, and a tendency of this sort has also been noted among agricultural innovations.

> Practices such as fertilizer applications, different fertilizer analyses, feed additives, weed sprays, or seed varieties may be tried on a sample basis and the results compared with those from previous practices. However, bulk milk tanks and milk parlors cannot be tried out easily on a small scale. A practice that can be tried on a limited basis will generally be adopted more rapidly than one that cannot.[34]

Fourth, there is the rate of reduction of the initial uncertainty regarding the innovation's performance. The nature of some innovations is such that information regarding their performance can be obtained quickly; others require a long time. For example, one of the great uncertainties regarding the byproduct coke oven was its length of life—a variable that could be measured only after a considerable number of years. Also, if the potential users have the sophistication and training that permit them to understand information about the innovation and to experiment with it effectively, their initial uncertainty is likely to be less and it is likely to decrease more rapidly over time.

Based on these hypotheses, Mansfield [50] has constructed and tested a simple model built largely around one central idea—that the probability that a firm will introduce a new technique increases with the proportion of firms already using it and the profitability of doing so, but decreases with the size of the investment required. When confronted with data for a small number of innovations, this model seems to stand up surprisingly well, an equation of the form predicted by the model explaining practically all of the variation in rates of diffusion. Although the model is still in the experimental stages, it seems to be a promising forecasting device.

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[34] Bohlen, et al. [8], p. 4.

5. Characteristics of Technical Leaders and Followers: Evidence From Agriculture

Rural sociologists and economists have made a large number of interesting studies of the characteristics of technical leaders and followers in agriculture. They often categorize farmers as innovators (the first 2.5 percent to adopt a new process), early adopters (the next 13.5 percent to adopt it), early majority (the next 34 percent), late majority (34 percent), and late adopters (final 16 percent). The studies indicate important differences among these five categories with regard to attitudes, values, social status, abilities, group memberships, and farm business characteristics.

First, consider attitudes and values. Innovators have more favorable attitudes toward science and are more likely than others to have direct contact with scientists. Laggards place more faith in agricultural "magic" and traditional beliefs than do innovators and early adopters. Innovators tend to place less value on being debt free and are more willing to borrow money. They have more venturesome attitudes and reach decisions more quickly than the others. Although the findings have not been entirely consistent, most studies have found laggards to be older than innovators.

Second, consider abilities and social status. Generally farmers who are quickest to adopt new techniques have the most formal education, have special mental abilities, and read more farm magazines and extension bulletins than laggards. Innovators have a higher social status than laggards. They generally have greater community prestige, larger farms, higher incomes, and more wealth than the others. However, their farming methods may not be respected by other farmers in the community.

Third, consider group memberships. Farmers who are early in using new techniques are more active in farm organizations, cooperatives, PTA's, and churches. Innovators are more active in statewide and countywide organizations; to the extent that laggards are in any groups at all, they are in neighborhood and community groups. Family ties are stronger for the late majority and laggards than for innovations and early adopters. The friendship patterns of the laggard tend to be restricted to his community, while those of the innovator tend to be more cosmopolitan. Innovators travel more widely than other farmers.

> Community norms affect the respect that innovators receive. In "progressive" communities, innovators may be looked to by their neighbors for information and advice. In "backward" communities, their farming methods are viewed with suspicion by their neighbors who are less prone to change.[35]

Fourth, consider the economic characteristics of the farmers and their farms. Innovators tend to have larger farms, higher gross farm incomes, greater farm efficiency, more specialized enterprises, and greater farm ownership. Of course, many of these characteristics are by no means surprising.

Finally, available data indicate that farmers' sources of information regarding innovations vary depending on the stage of the adoption process. Table 17 shows that mass media sources are most important at the awareness and interest stages. Neighbor and friends are most important at the evaluation and trial stages. Also, there is evidence of a "two-step flow of communication," as Katz [36] calls it. Early users tend to rely on information sources beyond their peer group's experience. After they begin to use the innovation, they become a model for their less expert peers who then imitate them.

6. Characteristics of Technical Leaders and Followers: Evidence from Industry [36]

Farms are small economic units, often with a single proprietor; thus it is easier to study the diffusion of an innovation in agriculture than in industry where firms often are gigantic organizations. Nonetheless, some work pertaining to industry has been done. Mansfield [51] studied the effect of seven characteristics of a firm and its operations on the rapidity of adoption of new techniques. These factors are the firm's (1) size; (2) expectation of profit from the innovation; (3) rate of growth; (4) profit level; (5) management

TABLE 17. RANK ORDER OF INFORMATION SOURCES BY STAGE IN THE ADOPTION PROCESS (AGRICULTURE)

Rank	Awareness (learns about a new idea or practice)	Interest (gets more information about it)	Evaluation (tries it out mentally)	Trial (tries a little)	Adoption (accepts it for full-scale use)
1	Mass media—radio, TV, newspapers, magazines.	Mass media	Friends and neighbors	Friends and neighbors	Friends and neighbors.
2	Friends and neighbors—mostly other farmers.	Friends and neighbors	Agricultural agencies	Agricultural agencies	Agricultural agencies.
3	Agricultural agencies—Extension, Vo Ag, etc.	Agricultural agencies	Dealers and salesmen	Dealers and salesmen	Mass media.
4	Dealers and salesmen	Dealers and salesmen	Mass media	Mass media	Dealers and salesmen.

SOURCE: Bohlen, J., et al., *Adopters of New Farm Ideas*, North Central Regional Extension Pub. No. 13, October 1961, table 1.

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[35] *Ibid.*, p. 6.

[36] Section 6 is taken largely from "Innovation in Individual Firms," *NSF Reviews of Data on Research and Development*, No. 34.

personnel's age; (6) liquidity; and (7) profit trend. First, in considering size, larger firms might be expected to introduce an innovation more quickly than small ones because: (1) Since larger firms have greater financial resources, more extensive engineering departments, better experimental facilities, and closer ties with equipment manufacturers, they can pioneer more cheaply and with less risk; (2) innovations are more adaptable to larger firms because they have a wider range of operating conditions; (3) since large firms have more units of a particular type of equipment, they are more likely to have at any one period some units which need replacement. Thus, an innovation designed to replace this equipment can be more quickly adopted by a larger firm. The findings substantiated this hypothesis, and results provided estimates of the quantitative effects of differences in size of firm on the speed at which an innovation is introduced.

Second, in considering expected profit from the innovation, the higher the expected return, the quicker the innovation could be expected to be adopted. Introduction of a new technique would be delayed if the return were not deemed adequate to offset the risk. Mansfield could obtain only partial data on the profit expectation of the various innovations; thus he was handicapped in drawing conclusions from tests of this hypothesis. However, available data strongly indicated that the investment's profitability is important in determining how rapidly an innovation is adopted. Moreover, estimates were obtained of the quantitative effects of this factor on a firm's rate of response.

Third, in considering the firm's growth rate, the more rapidly a firm is growing, the more responsive it could be expected to be in adopting an innovation. An expanding firm can introduce an innovation into new plants, whereas one that is not growing must wait until it can profitably replace existing equipment. Several other studies also suggest that this factor may often be important. However, the results of Mansfield's study revealed no close relationship between a firm's rate of growth and the rate at which it adopts an innovation nor was the effect of the factor statistically significant. Fourth, in considering profit level, more prosperous firms might be expected to adopt a new technique more quickly than those with low profit levels. Since less prosperous firms have smaller cash inflows and poorer credit ratings, they experience greater difficulty in financing the investment and are, therefore, in a less favorable position to take the risk involved in being one of the first to adopt an innovation. However, results of Mansfield's study showed no close relationship between a firm's profit and the rate at which it adopts an innovation; the effect of this factor was not statistically significant.

Fifth, in considering the age of management personnel, firms with younger top management personnel might be expected to adopt an innovation more quickly than those with older top management. It is often asserted that younger managements are less bound by traditional ways, and some evidence does indicate that this is true in agricultural enterprises. Yet no evidence of this relationship was found in this study, the effect of the factor being statistically nonsignificant.

Sixth, in considering liquidity, the more liquid firms, because they are better able to finance an investment, might be expected to begin using a new technique more quickly than the less liquid firms. The testing of this hypothesis was limited only to a few innovations because of the lack of sufficient data, and in these cases, the effect of liquidity on speed of response was not statistically significant.

Seventh, in considering profit trend, firms with decreasing profits might be expected to be more responsive to a new technique, because they would probably be stimulated to search more diligently for new alternatives of production. This hypothesis could be tested for only a few innovations because of insufficient data, and in these cases the effects of a firm's profit trend were not statistically significant.

7. Intrafirm Rates of Diffusion of an Innovation

Various factors influence the intrafirm rate of diffusion, that is, the rate at which a firm, once it has begun to use a new technique, continues to substitute it for older methods. To determine the factors contributory to a high rate of intrafirm diffusion, Mansfield [52] studied one of the most significant innovations developed in the interwar period, the diesel locomotive. The purpose was to determine how rapidly railroads substituted diesel power for steam once they had begun to dieselize.

Statistical results (based on ownership data) showed that about two-thirds of the variation in the rate of intrafirm dieselization among the railroads can be explained by the following four factors: Profit expectation of the investment in diesel locomotives, the date when a firm began to dieselize, size of the firm, and a firm's initial liquidity. Furthermore, the effect of each factor was in the expected direction and, with the exception of a firm's size, statistically significant.

Not statistically significant were the effects of three other factors included in the study: Variation in age distribution of a firm's steam locomotives, a firm's profit level, and its average length of haul. Other important factors were omitted in the study because they could not be measured satisfactorily. Among these were (1) the amount of sales pressure the diesel locomotive manufacturers exerted on firms; (2) the training of a firm's technical officers and top management and their attitudes toward risk taking; and (3) fluctuations in the profitability of a firm's investment in diesel locomotives.

8. Has There Been an Increase in the Rate of Diffusion?

Led by Charles Killingsworth [40], a number of economists have claimed that innovations spread much more rapidly now than in the past, presumably because of the development of improved communication channels, more sophisticated methods for determining when equipment should be replaced, and more favorable attitudes toward technological change. While the increase in the rate of diffusion is a question of considerable importance, available data are unfortunately extremely limited. Killingsworth admits that he has little or no quantitative evidence to support his proposition, and the only attempt to provide such evidence is contained in a 1961 study by Mansfield [50] of 12 innovations. The findings must be viewed with caution, since they pertain to only a few innovations and only four industries—iron and steel, railroads, bituminous coal, and brewing. Note too that they provide no information regarding the lag between invention and innovation.

To see whether the rate of diffusion has tended to increase over time, time was included as an explanatory variable in the analysis, as well as the profitability of the innovation and the size of the investment required to introduce it. In this way, an attempt was made to hold constant the effects of profitability and size of investment. While results indicated some apparent tendency for the rate of diffusion to increase over time, this tendency was very weak—the time interval between 20 and 80 percent adoption declined on the average by only four-tenths of 1 percent per year—and this could easily have been due to chance. Thus, this very limited evidence provides little or no basis for the belief that, all other things equal, innovations spread much more rapidly now than 20 years ago.

9. Performance-Based Federal Procurement

With the emphasis on economic growth, considerable attention has been devoted to ways of increasing the rate of innovation. One device prominent in recent discussions is performance-based Federal procurement. Its proponents claim that by formulating performance criteria rather than product specifications for the products, systems, and services it purchases, the Federal Government will (1) free industry to innovate, limited only by the requirement that certain specified functions be performed; (2) encourage cost reduction for the Government itself; and (3) serve as a pilot customer for technical innovations where it represents either a big enough market or one sufficiently free from local restrictions, codes, etc., to make innovating worth industry's while.

The Federal Government's role as a pilot customer is important in that State and local governments may be stimulated to apply new technologies by demonstrations of their successful use in Federal programs. There is considerable feeling in some quarters that the diffusion of new technology in State and local programs is impeded unnecessarily by the desire of local officials to buy locally [6], the influence of labor unions on building codes [58], lack of information by local officials [6], fragmentation of local government [1], and the tendency to look for "product" rather than "functional" needs [59].

Performance criteria are already being applied in a number of nondefense areas, such as the procurement of automobiles by the General Services Administration. Many observers believe that these criteria might be used in other areas as well, but according to Blaschke, three problems stand in the way: First, it is difficult to find the proper tradeoff between flexibility and standards that must be maintained. Second, there are administrative problems. Third, there is a problem in

> . . . finding technically competent officials who can review and analyze existing programs of nondefense procurement in light of new efficient alternatives whose technical characteristics might perform certain new functions. Therefore, determining the performance criteria and test methods could present a problem.[37]

10. Summary and Conclusions

The principal points made in part IV can be summarized as follows: First, the available evidence indicates that the average lag between invention and innovation has been about 14 years. For petroleum innovations, the standard deviation of this lag is about 5 years; in all other industries combined, it is about 16 years. Apparently, mechanical innovations required the shortest interval, and electronic innovations required the longest. In the industries we studied, process innovations were most likely to be introduced when an industry was operating at about 75 percent of capacity. Process innovation at the trough of the business cycle seems to have been discouraged by the meagerness of profits and the bleakness of future prospects; at the peak, it was discouraged by the lack of unutilized capacity. For product innovations, there was no evidence that the rate of innovation varied over the business cycle.

Second, the diffusion of a new technique has generally been a slow process. For example, measuring from the date of first successful commercial application, it took 20 years or more for all the major firms to install centralized traffic control, car retarders, byproduct coke ovens, and continuous annealing. Nonetheless, there has been considerable variation among innovations in their rate of diffusion. Although it sometimes took decades for firms to install a new technique, in other cases they imitated the innovator very quickly. In the 12 cases shown in figure 6, the number of years elapsing before half the firms had introduced an innovation varied from 0.9 to 15.

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[37] Blaschke [7], p. 39.

Third, an innovation's rate of diffusion seems to be determined in large part by four factors: The extent of the economic advantage of the innovation over older methods or products, the extent of the uncertainty associated with using the innovation when it first appears, the extent of the commitment required to try out the innovation, and the rate at which the initial uncertainty regarding the innovation's performance can be reduced. A simple mathematical model seems to perform surprisingly well, an equation of the form predicted by the model explaining practically all the variation in rates of diffusion among a small sample of innovations. Although the model is still in the experimental stages, it seems to be a promising forecasting device.

Fourth, among industrial firms, the size of a firm and the profitability of its investment in the innovation seem to be related directly to the speed with which it begins using the innovation. However, there is no evidence that a firm's speed of response is related to its rate of growth, profit level, liquidity, profit trend, or age of its management personnel. Among farmers, technical leaders seem to be people of relatively advanced formal education, higher social status, more cosmopolitan interests and social contacts. They have larger farms, higher gross farm incomes, greater farm efficiency, more specialized enterprises, and greater farm ownership than their slower competitors.

Fifth, there is very little evidence to test the proposition often put forth by economists and others that innovations tend to spread much more rapidly now than in the past. Holding other factors constant, there is a slight tendency in this direction, but this could be due to chance.

Finally, performance-based Federal procurement has received considerable attention as a possible spur to innovation. Its proponents claim that by formulating performance criteria rather than product specifications for the products, systems, and services it purchases, the Federal Government will free industry to innovate, reduce its cost, and serve as a pilot customer for technical innovations in areas where it represents a significant market. Also, they claim that State and local governments may be stimulated to apply new technologies once their successful application has been demonstrated in Federal programs.

Part V: CONCLUSION

It is difficult to summarize a paper which itself is a summary. Although the following are some of the more important points contained in the discussion, they give only a very sketchy and incomplete impression of the ground covered. They are listed to recall some of the general areas discussed and are by no means an adequate summary of the findings.

1. Economists define technological change as a shift in the production function, the production function being the relationship in a given firm or industry between the quantity of various inputs—capital, labor, land, etc.—and the maximum output that can be produced. On the basis of various simplifying assumptions regarding the nature of the production function and the way it shifts over time, measures have been devised of the rate at which it shifts. The result typically is a single number, x percent per year, which is the estimated rate of increase in the quantity of output derivable from a fixed set of inputs that has increased at x percent per year.

2. Two types of productivity indexes are in common use—partial and total. The most common form of partial productivity index is output per man-hour, which has important disadvantages as a measure of technological change, since it takes no account of changes over time in inputs other than labor. A better measure is the total productivity index, which relates changes in output to changes in both labor and capital. However, the total productivity index assumes implicitly that isoquants are straight lines. To remedy this, economists have devised a number of measures of the rate of technological change that are based on more reasonable assumptions regarding the shape of isoquants. Some of these measures assume that technological change is organizational; others, that it is capital-embodied.

3. Using any of these measures, the level of technology in the United States seems to have increased considerably throughout this century, with the average rate of technological change ranging from 1.5 to 2.5 percent per year, depending on the measure used. The rate of technological change seems to have varied perceptibly over time. Regardless of which measure is used, there is considerable evidence that it was higher after World War I than before. There is also some evidence that it was somewhat higher after World War II than before, but this is by no means a certainty.

4. The rate of growth of total productivity seems to have varied considerably among industries and nations. Over the long run, it seems to have been higher in communications and transportation than in mining, manufacturing, and farming. Within manufacturing, it seems to have been highest in rubber, transportation equipment, tobacco, chemicals, printing, glass, fabricated metals, textiles, and petroleum. Comparing the United States with Germany, Japan, Canada, and the United Kingdom during the postwar period, our rate of productivity growth seems lower than Germany's and Japan's, but at least equal to that of Canada and the United Kingdom.

5. These measures of the rate of technological change have been used to estimate the relative importance of technological change in the process of economic growth. Studies of a decade ago estimated that about 90 percent of the long-term increase in output per capita in the United States was attributable to technological change and other factors not directly associated with increases in the quantity of labor or capital. A more recent study concludes that the "advance of knowledge" contributed about 36 percent of the total increase in national income per person employed during 1929–57. These estimates undoubtedly are correct in indicating that technological change played a major role, perhaps the most important one, in generating economic growth, but beyond this, their accuracy cannot be taken very seriously.

6. Even the most sophisticated of these measures of the rate of technological change suffers from very important limitations. Because technological change is measured by its effects, and because its effects are measured by the growth of output unexplained by other factors, it is impossible to sort out technological change from the effects of whatever inputs are not included explicitly in the analysis. In addition, the customary measures suffer from their exclusive focus on output, narrowly defined. The available measures are, therefore, very imperfect guides, not precise measurements.

7. The rate of technological change in an industry depends to a large extent on the amount of resources devoted by members of the industry and by the Government to the improvement of the industry's technology. It depends too on the resources devoted to the improvement of technology in related industries (e.g., those supplying

materials and components). The amount of resources devoted by the Government depends on how closely the industry is related to the defense, medical, and other social needs for which the Government assumes primary responsibility, on the extent of the external economies generated by the relevant R. & D., and on various political factors. The amount of resources devoted by private industry depends heavily on the expected profitability of the investment.

8. Total R. & D. expenditures in the United States have increased spectacularly during the last several decades, and much of the R. & D. performed by industry and universities has been financed by the Federal Government. At present, three departments and agencies—the Department of Defense, the National Aeronautics and Space Administration, and the Atomic Energy Commission—account for about 90 percent of the R. & D. expenditures of the Federal Government. The primary purpose of these agencies' expenditures is to develop and improve weapons systems, push forward the Nation's space program, and develop atomic energy. The bulk of their expenditures is for development, not research, and the bulk of their research expenditures are in the physical and engineering sciences.

9. Although the independent inventor is still important, the R. & D. departments of industrial concerns are becoming a more and more important source of inventions. The performance of R. & D. is spread very unevenly among industries with R. & D. as a percent of sales highest in the aircraft, instruments, electrical equipment, and chemical industries. When company-financed R. & D. rather than R. & D. performance is considered, the differences among industries are reduced, but the industries remain in much the same rank order, with instruments, electrical equipment, chemicals, and machinery being highest.

10. It is extremely difficult for a firm to evaluate the returns from its R. & D. expenditures, a difficulty reflected in the process of industrial decision-making regarding R. & D. In the late fifties and early sixties, the expected returns from R. & D. seemed to have been higher than those from investment in plant and equipment. More recently, firms seem to be scrutinizing their R. & D. expenditures more carefully and to be somewhat less optimistic. With regard to the riskiness of industrial R. & D., studies indicate that more than 50 percent of a firm's R. & D. projects generally are failures and that estimates of the cost and completion date of a project generally are very poor.

11. A number of economists believe that there is an underinvestment in R. & D. because private returns do not adequately reflect social returns. Others charge that there is a malallocation of R. & D. expenditures. The commonly recommended remedies are Government grants and tax credits to support additional R. & D. in the areas of deficiency. Also, numerous proposals have been made to increase the efficiency of military and space R. & D. Unfortunately, there is far less evidence to guide public policies in these areas than one would like.

12. Economists have also been concerned for many years with the relationship between an industry's market structure and its technical progressiveness. Recently, there has been an emphasis on empirical studies applying modern econometric techniques to this question. The results, which are extremely tentative, provide little evidence that industrial giants are needed in all, or even most, industries to insure rapid technological change. However, this does not mean that very large firms are not needed in some industries. Again, unfortunately, there is far less evidence on this score than one would like.

13. Available evidence indicates that the average lag between invention and innovation has been about 14 years. For petroleum innovations, the standard deviation of this lag is about 5 years; in all other industries combined, it is about 16 years. Apparently, mechanical innovations required the shortest interval, and electronic innovations, the longest. In the industries studied, process innovations were most likely to be introduced when an industry was operating at about 75 percent of capacity. Apparently, process innovation at the trough of the business cycle was discouraged by the meagerness of profits and the bleakness of future prospects; at the peak, by the lack of unutilized capacity. For product innovations, there was no evidence that the rate of innovation varied over the business cycle.

14. The diffusion of a new technique has generally been a slow process. For example, from the date of first successful commercial application, it took 20 years or more for all major firms to install centralized traffic control, car retarders, byproduct coke ovens, and continuous annealing. Nonetheless, innovations have varied considerably in their rate of diffusion. Although decades passed before firms installed some new techniques, in other cases the innovator was imitated very quickly. In the 12 cases shown in figure 6, the number of years elapsing before half the firm had introduced an innovation varied from 0.9 to 15.

15. An innovation's rate of diffusion seems to be determined in large part by four factors: The extent of the economic advantage of the innovation over older methods or products; the extent of the uncertainty associated with using the innovation when it first appears; the extent of the commitment required to try out the innovation; and the rate at which the initial uncertainty regarding the innovation's performance can be reduced. A simple mathematical model seems to perform surprisingly well, with an equation of the form pre-

dicted by the model explaining practically all of the variation in rates of diffusion among a small sample of innovations. Although the model is still in the experimental stages, it seems to be a promising forecasting device.

16. Among industrial firms, the size of a firm and the profitability of its investment in the innovation seem to be directly related to the speed with which it begins using the innovation. However, there is no evidence that a firm's speed of response is related to the firm's rate of growth, profit level, liquidity, profit trend, or age of its management personnel. Among farmers, the technical leaders seem to be people of relatively advanced formal education, higher social status, more cosmopolitan interests, and social contacts. They also have larger farms, higher gross farm incomes, greater farm efficiency, more specialized enterprises, and greater farm ownership than their slower competitors.

17. There is very little evidence to test the proposition often put forth by economists and others that innovations tend to spread much more rapidly now than in the past. Holding other factors constant, there is a slight tendency in this direction, but it could be due to chance.

18. Performance-based Federal procurement has received considerable attention as a possible spur to innovation. Its proponents claim that by formulating performance criteria rather than product specifications for the products, systems, and services it purchases, the Federal Government will free industry to innovate, reduce its costs, and serve as a pilot customer for technical innovations in areas where it represents a significant market. Also, they claim that State and local governments may be stimulated to apply new technologies once their successful application has been demonstrated in Federal programs.

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Part 2

BY INDUSTRY

PRODUCTIVITY, TECHNOLOGY, AND EMPLOYMENT IN U.S. AGRICULTURE

Prepared for the Commission
by

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PREFACE

Nail C. Yucel, graduate student at Washington State University, contributed many helpful ideas and assisted in the preparation of this report. Valuable assistance was also gained from several staff members of the Economic Research Service, U.S. Department of Agriculture. Special computations by Donald D. Durost and a staff paper by Robert C. McElroy, entitled "Technology, Automation, and Economic Progress in Agriculture," were especially helpful.

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Productivity, Technology, and Employment in U.S. Agriculture

Introduction

During the past 25 years, output per man-hour and per unit of input in U.S. agriculture have advanced rapidly in comparison with agriculture's earlier productivity gains and with current rates of productivity advances in the nonfarm portion of the economy. The increases in efficiency have been accompanied by major adjustments in the organization of agricultural production and in the combinations of inputs used. By all odds, the most important adjustment has been a substantial reduction in the total amount of labor used in agriculture. The laborsaving technologies that made this reduction possible have made a major contribution to growth in agricultural efficiency, but the adjustments have led to difficult problems as large numbers of farmers, farmworkers, and rural youth have had to make the transfer to other employment.

The purpose of this paper will be to review the major technological changes that have been the basic source of improved productivity in agriculture and discuss the interrelations of technological change, adjustments in agricultural employment, and welfare of farm and rural people. In conclusion, future prospects in agriculture will be discussed and certain guidelines to remedial action suggested.

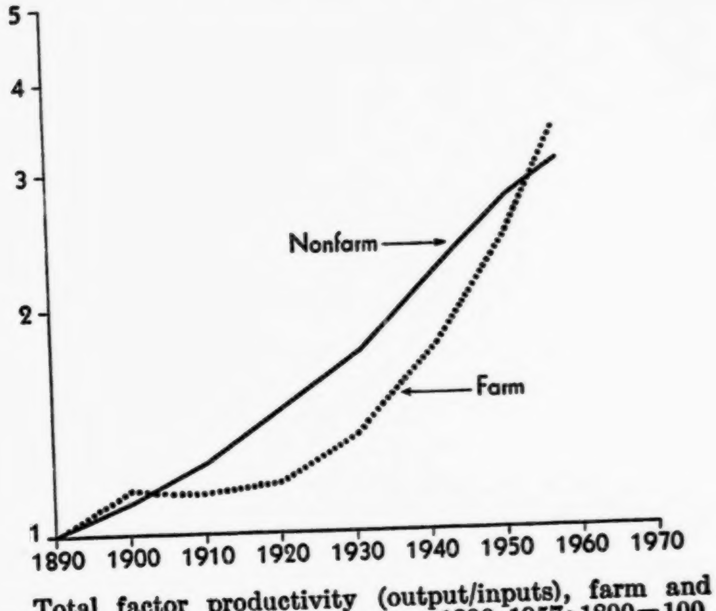
Output, Inputs, and Productivity in Agriculture

For several decades prior to 1940, agriculture lagged behind the rest of the U.S. economy in the achievement of higher productivity. The difference is clearly evident in figure 1 which shows total factor productivity (output/inputs) for the farm and nonfarm portions of the economy as measured by Kendrick.[1] A ratio scale is used so that comparison of slopes on the trend lines indicates relative rates of growth in the indexes. From 1890 to 1920, productivity in farming grew by only about one-third as much as productivity in the nonfarm portion of the economy. During the next 20 years, from 1920 to 1940, productivity advances in agriculture approximately paralleled those in the rest of the economy. Then, from 1940 on, agriculture increased its productivity per unit of input much more rapidly than did the rest of the economy. By 1957, agriculture was able to overcome the earlier deficit and show a greater total gain in productivity for the entire period 1890–1957 than the nonfarm portion.

The progress over time of the productivity ratio and its two components—total output and total input—are shown in figure 2. The indexes in figure 2 reflect changes in farm output and inputs used, with components valued at constant prices. They are derived from U.S. Department of Agriculture series and differ somewhat from Kendrick's estimates.

During the period from 1890 to 1940, productivity gains were very small. Output grew but inputs were increasing almost as rapidly. During the two decades, 1900–20, use of inputs in agriculture actually advanced more rapidly than output

FIGURE 1. *Total Factor Productivity, Farm and Nonfarm*



Total factor productivity (output/inputs), farm and nonfarm segments of U.S. economy, 1890–1957; 1890=100.

Year	1890	1900	1910	1920	1930	1940	1950	1957
Nonfarm	100	111	124	145	170	219	271	307
Farm	100	115	114	116	135	173	241	335

SOURCE: Kendrick, *Productivity Trends in the United States*, NBER, 1961.

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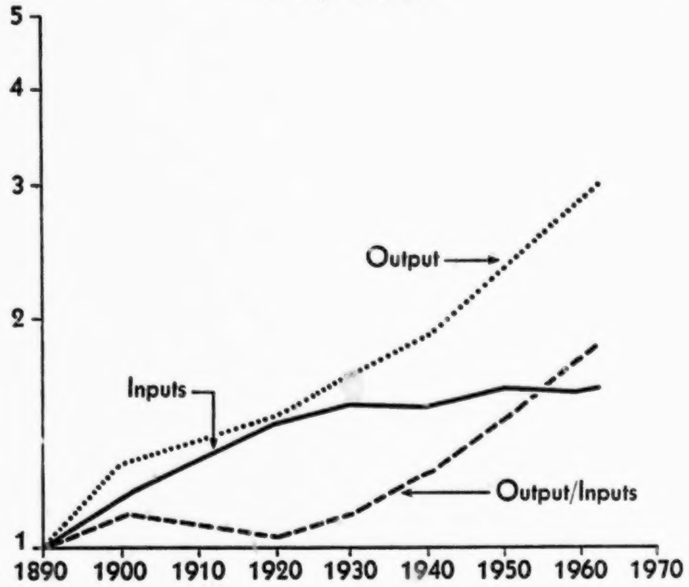
[1] John W. Kendrick, *Productivity Trends in the United States*, National Bureau of Economic Research, No. 71, General Series, 1961.

FIGURE 2. ***Output, Inputs, and Output Per Unit of Input in Agriculture***



Output, inputs, and output per unit of input in U.S. agriculture, 1890–1963; 1890=100.

Year	1890	1900	1910	1920	1930	1940	1950	1960	1963
Input	100	116	130	145	154	152	162	160	162
Output	100	130	138	150	170	190	236	285	303
Productivity	100	112	107	104	111	125	147	178	188

SOURCE: Barton and Durost, "Productivity of U.S. Agriculture—A Long-Term Perspective," *Journal of the National Productivity Council*, New Delhi, forthcoming.

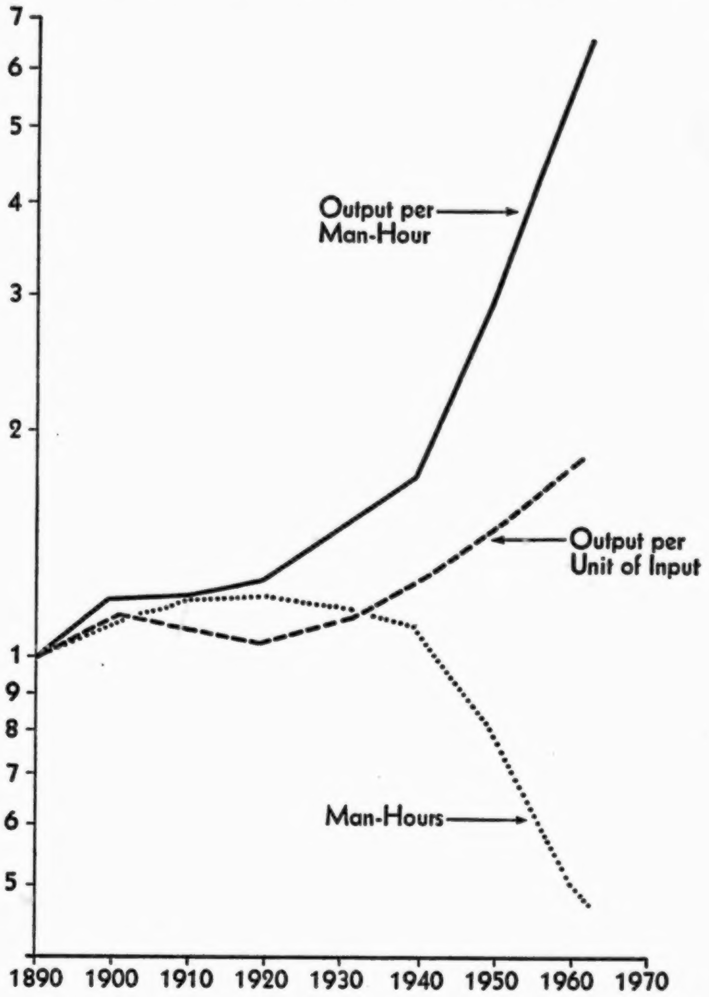
and the ratio of output to inputs fell. During that time, agriculture was making large additions to acreage farmed but no major technological improvements were coming into widespread use. Beginning with 1920, the pace of adding inputs slackened while output continued to grow. Small productivity gains began to be achieved. Even during the depression-dominated decade from 1930 to 1940, productivity was growing, in part because there was a net reduction in the total amount of inputs used in agricultural production.

Relatively high rates of 2 percent per year gain in productivity began during the 1940's and have continued to the present. This high rate of gain in output per unit of input has been achieved by holding the amount of inputs used virtually constant while continuing to increase output. In 1963, aggregate input use in agriculture was exactly the same as it had been in 1950 and only 5 percent above its 1940 level. Output grew by 28 percent during the 14-year span, 1950–63, and 60 percent from 1940 to 1963.

Recent changes in the amount of labor used in agriculture and output per man-hour have been even more dramatic than changes in total inputs and output per unit of input (fig. 3). By 1910, the amount of labor used for farmwork was already close to its peak, more than 20 years before total input use reached a peak. From 1910 to 1930, the man-hours of labor used in agriculture remained virtually constant at about 23 billion man-hours and productivity of labor rose slowly with the slight upward trend in total farm output.

During the decade from 1930 to 1940, a slow but unmistakable decline began in the total amount of labor used by agriculture. From 1940 on, the decline in agricultural use of labor was more rapid. Since farm output also grew more rapidly after 1940, the combined effect was a large increase in output per man-hour of approximately 5 percent per year—more than double the rate of gain in output per unit of input.

FIGURE 3. ***Labor Use and Productivity in Agriculture***



Labor used in agriculture, output per man-hour and output per unit of input, 1890–1963; 1890=100.

Year	1890	1900	1910	1920	1930	1940	1950	1960	1963
Output per man-hour	100	118	118	125	146	173	291	559	659
Output per unit input	100	112	107	104	111	125	147	178	188
Man-hours	100	110	117	120	116	110	81	51	46

SOURCE: U.S. Department of Agriculture, Statistical Bulletin No. 233, 1965. Barton and Durost, "Productivity of U.S. Agriculture—A Long-Term Perspective," *Journal of the National Productivity Council*, New Delhi, forthcoming.

Improved technology has played the major role in advancing output and efficiency of resource use in agriculture. Output increasing technological changes have increased output per producing unit—per acre or per animal—making it possible to meet growing demands without putting more resources into agriculture. Laborsaving innovations have decreased the labor requirements for farmwork and raised the efficiency with which agricultural operations are performed. Both types of innovations contribute to increased ratios of output/inputs and output/man-hour. The output-increasing innovations raise the numerator and the laborsaving innovations make it possible to lower the denominator.

Output-Increasing Technology and Output Levels

The American public has for many years shown considerable interest in the development of output-increasing technologies that will, in popular phraseology, "cause two blades of grass to grow where only one grew before." Back of this public interest has been concern that, unless means of increasing farm output were devised, the Nation would be faced with higher food prices and perhaps actual shortages of food.

The concern was well founded. The approaching end of the supply of virgin lands was apparent well before the turn of the century. By 1920, almost all cultivable lands had been brought into use. From then on, increases in food production had to come either from the use of more labor and capital to cultivate the land more intensively or the development of new, more productive technologies. The hopelessness of depending on intensification alone had been well stated nearly 2 centuries ago by Malthus.[2] That approach would lead inevitably to declining productivity per unit of labor and capital, increasing resource requirements per unit of food produced and eventually a general regression in living standards.

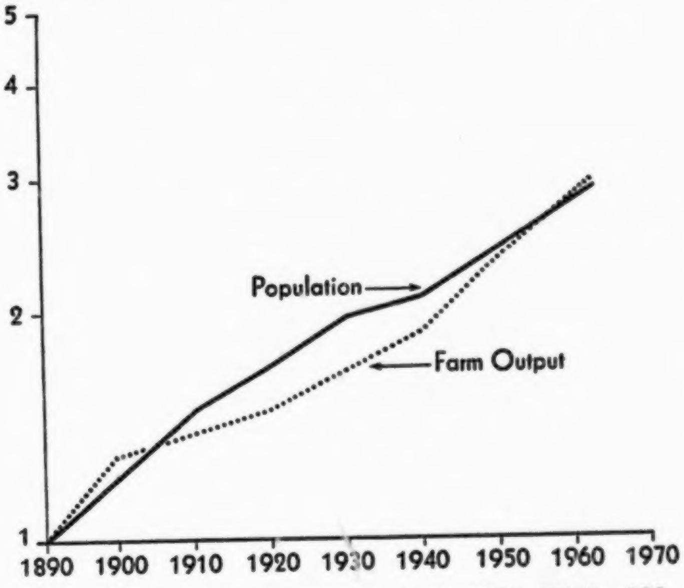
The logical and farsighted approach was to strive for the improved technology that was needed to provide adequate food without demanding more labor and capital. The Land Grant University System of teaching, research, and extension education was set up about 100 years ago along with the U.S. Department of Agriculture and Federal, State, and local funds appropriated to support work toward that end.

The results have been quite gratifying. Farmers have welcomed the new innovations. Private industry has joined in with its own research program in several areas. The result has been that growth in farm output has been adequate to meet the food needs of a growing population (fig. 4). And this has been achieved without the need for intensification. The total inputs of labor and capital, taken together, have not increased significantly for several decades.

It would be impossible to enumerate all the technological innovations that have made these increases in output possible. A brief summary of major sources of increased farm output is shown in table 1. During the period from 1919–21 to 1938–40, the reduction in farm-produced power (work animals) accounted for 51 percent of the total increase in output and increasing crop production per acre accounted for 34 percent. During the period from 1940–41 to 1955, increased crop production per acre added about twice as much to output as did the further reduction in farm-produced power, and additional product added by livestock also made an important contribution to increased output. Unfortunately, a similar comprehensive analysis is not available for the period from 1955 to the present. However, it is safe to say that such a study would show continued growth in importance of crop production per acre and a very sharp decrease in the contribution of reduction in farm-produced power.

The importance of the reduction in farm-produced power to increased farm output is often not fully appreciated. In 1920, when the number of horses and mules on farms was at its peak, 80 million acres of cropland were used just to supply hay and grain to the 27 million draft animals on

FIGURE 4. *U.S. Farm Output and U.S. Population*



Farm output and population, 1890–1963; 1890=100.

Year	1890	1900	1910	1920	1930	1940	1950	1960	1963
Population	100	121	147	169	196	210	240	285	299
Farm output	100	130	138	150	170	190	236	285	303

SOURCE: *Agricultural Statistics*, 1964.

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[2] Thomas Malthus, *Essay on Population* (1st ed., 1798) 6th ed., London, Ward, Locke & Co., 1826.

TABLE 1. PERCENTAGE CONTRIBUTION OF MAJOR SOURCES OF INCREASE IN FARM OUTPUT, 1919–21 TO 1938–40 AND 1940–41 TO 1955

Source of increase	Percentage of total increase	
	1919–21 to 1938–40	1940–41 to 1955
Increased crop production per acre	34	43
Reduction in farm-produced power	51	23
Change in product added by livestock	15	25
Net effect of other sources	0	9
Total	100	100

SOURCE: Donald D. Durost and Glen T. Barton, "Changing Sources of Farm Output," U.S. Department of Agriculture, Production Research Report No. 36, 1960, p. 17.

farms. That acreage amounted to 20 percent of all land used for crop production. As farm tractors began to replace horses and mules, the land that had been committed to supplying their feed was released to produce crops for human consumption or feed for producing meat and livestock products. By 1940, the replacement of horses and mules was about half completed. By 1960, the amount of feed going to horses and mules had fallen to about 5 percent of its 1920 level. At the present time, only about 1 percent of the cropland in the United States is used to supply feed for horses and mules. There is essentially no further opportunity for adding to farm output by reducing the numbers of horses and mules.[3]

Increased crop production per acre has been a more durable source of increased farm output and promises to be the major source of future gains. From 1910 to 1930, virtually no increase had been recorded in the U.S. Department of Agriculture's index of crop production per acre nor in the average yields of the major crops. Then from 1930 to 1950, the index of crop production per acre grew by 25 percent—an average annual increase of 1.1 percent. From 1950 to 1964, the index grew by 36 percent—slightly more than 2 percent per year. In 1964, crop production per acre was approximately two-thirds greater than it had been during the period 1910–30. Many of the major crops show even greater increases in yield.

Several technological developments contributed to the increase in crop production per acre. By far the most important of these has been the use of chemical fertilizers. Until the 20th century, the process of plant feeding had been based primarily on the use of natural organic materials such as animal and plant wastes, and legume crops grown especially for their nitrogen-supplying character. These had been laborious to apply to the land and limited in supply. Industrially produced chemical fertilizers revolutionized the process of plant production.

By 1910, commercial fertilizers were already being used in fairly large amounts in certain parts of the country, notably the South. Use of these products grew slowly during the 1920's and 1930's. Even so, by 1940, increased use of fertilizer was credited as the source of one-fourth of the increase in crop production during the preceding 20 years.[4]

During the 1940's, the amount of commercial fertilizer use more than doubled. This alone accounted for one-half of the increase in crop production per acre and 20 percent of the total increase in farm output. In the 1950's, increased fertilizer use contributed two-thirds of the increase in crop production and almost one-fourth of the increase in total farm ouput. The use of fertilizer doubled again from 1950 to 1962 and increased by another 20 percent in just 2 years from 1962 to 1964.

The importance of fertilizer to crop yields extends beyond its immediate contribution. The availability of fertilizers has made it possible to get more benefit out of higher yielding varieties, irrigation, and other inputs.

Other factors have made important contributions to increased crop production. Hybrid corn and sorghum seed increased yields of those crops some 20 percent. Irrigated cropland has grown from 14 million acres in 1920 to 33 million acres in 1959 and to an estimated 37 million acres in 1964. Pesticides and other agricultural chemicals, totaling 634 million pounds in 1962 and having a sales value of $326 million, have reduced weed and pest damage to growing crops and thereby increased yields. Better timing of farm operations has reduced weather losses. Better management throughout the production process has also made a contribution.

The product added by livestock has also been contributing an increasing amount to farm output. (Product added by livestock is the amount by which output of livestock exceeds the amount of farm-produced feeds that livestock consume.) Better breeding of animals, more scientific care, scientific mixing of rations and better control of diseases have all contributed to the rise in product added by livestock. Significantly, the number of breeding units of livestock has increased very little since 1920 but livestock production per breeding unit has doubled.

Many of these output-increasing technologies have been highly profitable to the individual farmer when no account was taken of their eventual effect upon the supply and price of farm products. Hybrid corn seed that added $2 per acre to costs and $10 to $30 to gross returns was certainly a good investment. The rate of return on expenditures for fertilizer has generally been greater than $2 per $1 spent. However, when all farmers adopted the new technologies, large aggregate increases in output began to make their weight felt on markets and prices. It soon became apparent that the new technologies had the capability of expanding output more rapidly than the market for farm products was growing. Concern about the adequacy of food supplies changed to a concern about the adequacy of markets for farm products.

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[3] Durost and Barton, *op. cit.*, p. 14.

[4] Durost and Barton, *op. cit.*, p. 26.

If the markets for farm products could be easily expanded, an "excess" growth of production capacity would have caused no problems. Unfortunately, the markets for farm products have been unresponsive to market expansion efforts.

The difficulty arises from the fact that more than 75 percent of agricultural output is used domestically for food and Americans are, by and large, already well fed and quite disinterested in consuming more food per person. Consumers' incomes are rising but most additional spending is for products other than food. The small additional amount that is spent for food items goes mostly for more "built-in maid service," and very little additional farm output is sold. Lowered prices, advertising, and other market expansion efforts seem to have little effect on total food consumption.[5] Growth in population is about the only force that consistently works to expand domestic food markets.

Two possibilities of circumventing the unresponsiveness of the food market that have been considered are to develop markets for nonfood uses of farm products and to increase food exports to other countries. The nonfood markets have proven difficult to develop and hold. If anything, agriculture is losing ground to other suppliers. The export market has shown considerable growth in recent years, accounting for approximately 20 percent of the growth in total utilization of farm products from 1950 to 1963. However, the big boost given to exports by growth of foreign assistance during the 1950's may not be duplicated in the near future. Future growth will depend importantly upon growth in purchasing power of countries now existing on a very minimal diet.

Since growth in the market for farm products could not be speeded up to equal growth in output capacity, it has been necessary to reduce the overall size of the farm productive plant. Output had to correspond fairly closely with markets, either through the operation of supply and demand or through Government regulation.

One indication of the extent to which output-increasing technology has led to a reduction in the size of the farm industry is the decrease in acreage of land used for crop production. From 1929 to 1964, the total acres of crops harvested declined from 365 million acres to approximately 300 million. Data in table 2 show very definitely that increases in yields of the major crops have, in most cases, been accompanied by decreases in acreage. With some crops, the immediate cause of the decline in acreage was an acreage control program. With others, economic forces alone brought about a voluntary decrease in acreage as yield increases caused supply to outrun demand and resulted in a downward pressure on prices. Among the major crops, only grain sorghum and soybean acreages have run counter to the trend.

The reduction in acreage used for crops has, in turn, had significant effect upon the total amount of labor required in agriculture. The reductions in acreages of major crops from 1929 to 1965 would have reduced the total amount of labor required for crop production by 33 percent even if there had been no reduction in the amount of labor required per acre of crop.[6] This source of reduced labor requirements alone would account for a 3.6 billion man-hour reduction in

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[5] John M. Wetmore, Martin Abel, Elmer W. Learn, and Willard W. Cochrane, "Expanding the Demand for Farm Products in the United States," University of Minnesota, Technical Bulletin 231, 1959, p. 101.

[6] The reduction in labor due to decreased crop acreages was calculated as follows: (1) 1929 harvested acreages for 15 major crops were multiplied by 1929 labor requirements per acre for each crop and summed to give a total labor requirement in 1929; (2) 1965 harvested acreages of each crop were multiplied by the 1929 labor requirements per harvested acre and summed to give total labor required for 1965 acreage with 1929 labor technology; (3) (1) minus (2) was divided by (1), to give the percentage decline in labor due to decline in crop acreages.

TABLE 2. YIELD AND ACREAGE HARVESTED, 10 SELECTED MAJOR CROPS, 1929, 1949, AND 1965 AND CHANGE, 1929–65

Crop	Yield per acre harvested				Acreage harvested			Change, 1929–65	
	Unit	1929 [1]	1949	1965 [2]	1929	1949	1965 [2]	Yield	Acreage
					1,000 acres	1,000 acres	1,000 acres	Percent	Percent
Corn	Bushels	27	39	73	97,805	85,602	57,245	+171	−42
Oats	do	30	33	51	38,153	39,236	19,357	+37	−49
Barley	do	22	24	43	13,564	9,872	9,519	+95	−30
Grain sorghum	do	18	23	48	3,523	6,592	13,506	+167	+283
Wheat	do	14	15	27	63,292	75,910	49,846	+93	−21
Soybeans	do	13	23	25	708	10,482	34,686	+92	+3,900
Cotton	Pounds	155	284	534	43,232	27,439	13,632	+244	−68
Tobacco	do	773	1,209	2,038	1,980	1,623	983	+164	−50
Potatoes	Hundredweight	65	129	206	3,030	1,758	1,413	+217	−53
Hay	Tons	1.2	1.4	1.8	69,531	71,464	67,939	+50	−2

[1] Average 1925–29.
[2] Indicated as of Oct. 1, 1965.

agricultural labor. Even if a liberal allowance is made for labor to harvest the heavier yields, the reduction is not likely to have been less than 2 billion man-hours.

The reduction in labor needs, calculated on the assumption that labor required per acre had not declined since 1929, reflects both a decline in total crop acreage and a shift away from labor-intensive crops. The acreage of the three crops having highest labor requirements per acre—cotton, tobacco, and potatoes—was decreased from a total of 48 million acres in 1929 to a total of only 16 million acres in 1965. Declines of 50 to 70 percent in acreage of these crops can be contrasted with decreases of 30 percent in small grains (oats, barley, and wheat) and 2 percent in hay, both of which have low labor requirements per acre. The three labor-intensive crops had combined labor requirements in 1929 of 5 billion man-hours—approximately 40 percent of all labor used for crop production. By 1965, the decrease in acreage of these crops alone would have been sufficient to reduce their labor requirement by 3.1 billion man-hours.

The pattern of greatest decrease in acreage occurring in the labor-intensive crops may indicate that high labor use per acre and per unit of output is a cause of relatively rapid decline in acreage. Finding conclusive evidence that this is in fact so would be very difficult. However, it has been asserted that a high-labor requirement per bushel of output has been a factor causing corn acreage to decline relatively more rapidly than the acreage of other grains.[7] According to Johnson and Gustafson, the yield advantage of corn has not been great enough to offset its comparatively high labor requirement per unit of output.

Laborsaving Technology

Although rising yields have, indirectly, brought about a significant reduction in agricultural labor needs, the largest reduction has come through adoption of laborsaving technologies. The results of substantial progress in laborsaving technology are evident in the decline of man-hour requirements per acre and per animal shown in table 3. For most major crops, man-hours required per acre of crop dropped to one-third or less during the 35-year interval from 1925–29 to 1960–64. Only tobacco production experienced an increase in labor needs per acre due to the effect of rising yields on harvest labor requirements. Data for livestock enterprises, while not strictly comparable, definitely show a downward trend in man-hours per animal. In total, a reduction in labor needs during the period 1929 to 1964 of 11 billion man-hours is accounted for by reduced labor requirements per acre and per animal.

From 1920 on, the number of tractors on farms increased while the numbers of horses and mules decreased. The progress of these changes is shown in table 4. By 1960, the changeover to tractors was virtually complete and the 3.1 million horses and mules left on farms performed little if any farmwork.

Since the coming of the tractor, mechanization in agriculture has continued to eliminate hand-labor tasks. Corn and cotton pickers have mechanized the harvest of these crops on most farms. Hay harvesting has been more completely mechanized. Machines and chemicals have substituted for much of the hand labor in weed control. Recently, some truly ingenious fruit and vegetable harvesters have begun to replace the large amounts of hand labor used on those crops.

In recent years, an increasing portion of the advances in farm mechanization have come with a new generation of larger, faster, and more efficient machines. The gains are seldom as great as those that come from first mechanization; however, they still can be quite sizable in some cases. Often new machines are designed to incorporate in one machine the tasks that had been performed by two or three old machines. A current example is the rapidly spreading corn "picker-sheller."

Few farm tasks could be called automated in the sense that a pushbutton factory or assembly-line is automated. A few livestock "factories" come close to being fully automated but most field operations have several difficulties[8] to overcome before true automation comes. Some of the difficulties are of an engineering nature, such as the need for developing an adequate guidance system for a driverless tractor. However, much of

TABLE 3. LABOR REQUIREMENTS PER UNIT FOR SELECTED ENTERPRISES, 1925–29, 1945–49, AND 1960–64

Enterprise	Unit	Man-hours required		
		1920–29	1940–49	1960–64
Corn for grain	Acre	30.3	19.2	6.8
Wheat	do	10.5	5.7	2.9
Tobacco	do	370.0	460.0	493.0
Cotton	do	96.0	83.0	47.0
Vegetables, all	do	----------	[1] 119.0	[2] 90.0
Hay	do	12.0	8.4	5.4
Potatoes	do	73.1	68.5	48.1
Milk cows	Cow	145.0	129.0	96.0
Cattle and calves	Hundredweight of beef.	4.3	4.0	2.9
Broilers	100 birds	32.0	15.6	3.3

[1] As of 1939. [2] As of 1959.

SOURCE: Robert C. McElroy, Reuben W. Hecht, and Earle E. Gavett, "Labor Used to Produce Field Crops," U.S. Department of Agriculture, Statistical Bulletin No. 346, 1964.

Reuben W. Hecht, "Labor Used to Produce Livestock," U.S. Department of Agriculture, Statistical Bulletin No. 336, 1963.

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[7] D. Gale Johnson and Robert L. Gustafson, *Grain Yields and the American Food Supply*, University of Chicago Press, 1962, pp. 125–129.

[8] Harold E. Pinches, "Revolution in Agriculture," *Power To Produce, The Yearbook of Agriculture*, 1960, U.S. Department of Agriculture, pp. 1–9.

TABLE 4. PROGRESS OF MECHANIZATION ON FARMS: NUMBERS OF HORSES AND MULES, TRACTORS, AND MAJOR HARVESTING MACHINES; VALUE OF MACHINERY AND EQUIPMENT; AND INDEX OF MECHANICAL POWER AND MACHINERY INPUTS; SELECTED YEARS 1910–64

Year	Horses and mules	Tractors	Harvesting machines [1]	Value of machinery and equipment	Index of mechanical power and machinery
	[In millions]				[1957–59 =100]
1910	24.2	(2)	(2)	(3)	20
1920	25.7	0.2	(2)	(3)	32
1930	19.1	.9	0.2	(3)	40
1940	14.5	1.6	.4	$3,060	42
1950	7.8	3.4	1.4	11,314	86
1960	3.1	4.7	2.8	18,613	100
1964	(3)	4.7	3.0	20,082	101

[1] Grain combines, cornpickers and picker-shellers, pickup balers, and field forage harvesters.
[2] Less than 0.1 million.
[3] Strictly comparable data not available.

SOURCES: *Changes in Farm Production and Efficiency*, U.S. Department of Agriculture, Statistical Bulletin 233, 1965. *Balance Sheet of Agriculture*, 1964.

the reason for farm mechanization and automation not having proceeded further and faster lies in the difficulty of paying for a large complex machine out of labor and other costs saved in a farm operation.

Seasonality of farmwork in particular causes machine costs per hour of work performed to be high. Tractors are used more than any other farm machine; yet, a recent study found average use to be only 600 hours per year.[9] Low rates of usage mean that ownership costs—depreciation, interest, taxes, and insurance—are high per hour of use. As a result, only machines that save large amounts of labor per hour of machine use or reduce other costs can be economically justified.

The small size of many farm businesses also makes mechanization more difficult and less profitable than it might otherwise be. The difficulties of fitting together a balanced "line" of equipment for a small farm may result in having some machines that are too large for the business. Specialized machines that are highly efficient but costly if operated on small acreages are not feasible for the small farmer. The small farmer also may be hampered by not being able to hire specialized mechanics and machine operators as do industrial firms and a few very large farms.

Despite these handicaps, mechanization of agriculture has progressed at a rapid pace. Table 4 shows the value of machinery and equipment on farms is now almost seven times as great as in 1940. The total inputs from machinery and mechanical power have increased by 2½ times after correction is made for changes in the level of prices.

Mechanization in agriculture has occurred, despite difficulties, primarily because of economic gains it brought. In the first place, it has been possible, by using machinery, to perform farmwork with less total input of labor, power, and machinery. From 1940 to 1964, the total amount of these three inputs, plus an allowance for power from horses, declined by 40 percent. During the same time, the percentage of mechanical power and machinery in the total increased from 14 percent to 48 percent. A small part of the decline, no more than 8 out of the 40 percent,[10] may be due to the decline in crop acreages discussed above. The remainder of the reduction in inputs can be attributed to increased efficiency of performing work with relatively large amounts of machinery rather than with large amounts of labor and animal power.

A second incentive to mechanization has been provided by a definite increase in the cost of labor relative to the costs of other inputs. In figure 5, farm wage rates are compared with the index of machinery prices and costs of motor supplies and fertilizer. The index of wage rates is currently more than 675 percent of the 1910–14 level whereas machinery prices have only risen to 405 percent and motor supplies to 175 percent of their 1910–13 levels. Farm operators, attempting to keep costs per unit of output low, have obviously found it increasingly profitable to substitute relatively cheap machinery for relatively expensive labor.

Farm Employment and Rural Population

A decline in farm employment followed inevitably from the reductions in labor needed for farmwork. The exodus of workers from agriculture has, by any measure, been of large magnitude. When the decline began, around 1920, there were 11.5 million persons employed[11] in agriculture. By 1940, agricultural employment had declined to 9.5 million persons. In 1964 it was only 4.7 million persons—about 40 percent of the 1920 employment.

Agricultural employment grew less rapidly than employment in the nonfarm economy for some time before the actual decline in farm employment began. Lebergott[12] has calculated that, because of the relatively slow rate of growth and

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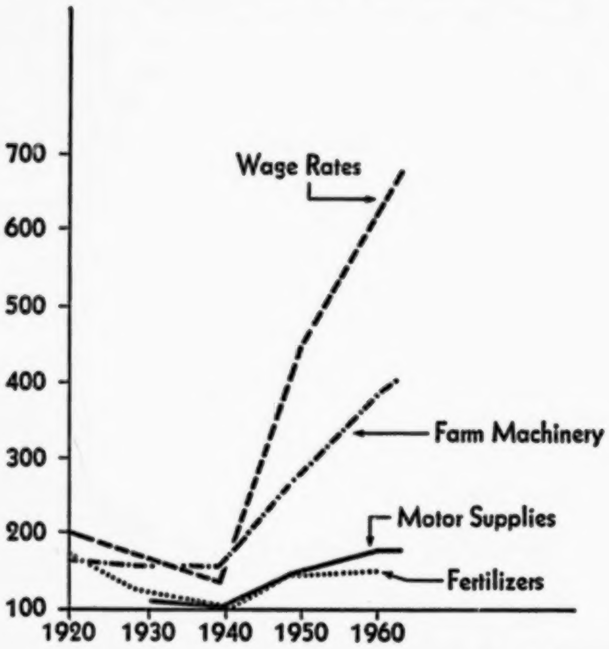
[9] Julius J. Csorba, "Farm Tractors: Trends in Type, Size, Age and Use," U.S. Department of Agriculture, Information Bulletin Number 231, 1960.

[10] The maximum estimate of labor reduction due to declining acreage was 3.6 billion man-hours. Allowance for added harvest labor might bring this as low as 2.0 billion man-hours or less than 8.5 percent of total agricultural labor needs (both crops and livestock) in 1929. The labor reduction came from a decline of labor-intensive crops. Thus, it would be a larger percentage decrease than the reduction of total labor, power, and machinery on all crops that had declining acreage. Therefore, it is reasonable to expect that the decline in total labor, power, and machinery would be less than 8 percent.

[11] Bureau of Labor Statistics estimates of employment by industry.

[12] Stanley Lebergott, *Manpower in Economic Growth; the American Record Since 1800*, McGraw-Hill, 1964.

FIGURE 5. *Trends in Prices of Agricultural Inputs*



Prices paid by farmers for items used in production 1920–63; 1910–14=100.

Year	1920	1930	1940	1950	1960	1963
Farm wage rates	199	165	140	448	622	675
Farm machinery	163	152	154	282	381	405
Motor supplies	--------	114	102	150	175	175
Fertilizers	167	123	99	149	153	152

SOURCE: *Agricultural Statistics*, 1964.

eventual decline in farm employment, agriculture was employing 22 million fewer workers in 1958 than would have been the case if it had held its 1900 share of the work force. The 22-million workers "released" from agriculture made up three-fourths of the work force added by expanding industries such as the trades and services. All other industries whose employment grew less rapidly than the rate of growth in total U.S. employment released a total of only 7.5 million workers—one-third as many as agriculture alone. Thus, to an important extent, declining farm employment has provided the labor force for "growth industries."

Although the movement of workers out of agriculture has been rapid, it has not been rapid enough to bring the agricultural labor force into balance with labor needs under evolving technologies. The primary evidence of imbalance is a persistently low level of agricultural labor earnings as compared with earnings in the rest of the economy. Strand and Heady [13] calculated a labor income per worker on commercial farms of $1,208 in 1949—production workers in manufacturing industries averaged approximately $3,000 per year at that time. In a more recent study, Johnson [14] concluded that "per capita farm incomes would have to increase about 50.4 percent from the 1956 level if comparable labor is to receive the same returns in the farm and nonfarm sectors." Still more recently, Tweeten's [15] estimates for 1959 show average labor incomes of farm operators of $3,000 per year, approximately two-thirds as much as factory workers' earnings.

The incomes of hired farmworkers have also been low in comparison to wages in nonfarm jobs. In 1963, hired farmworkers averaged only $6.35 per day of work and only 107 days of work per year.[16] Only nonmigratory workers in the West averaged much above this amount. Farmworkers in the South received less than the national average. Significantly, farmworkers who had some nonfarm work had average daily earnings at their nonfarm job that were 50 percent above their earnings at farm work.

The organization of firms and employment in agriculture is conducive to the development of low-labor returns during a period of declining labor needs. Only about 7 percent of all agricultural workers are regular hired employees. The largest number, about two-thirds, are self-employed individuals and members of their families. The rest, about one-fourth, are more or less casual employees who work only part time or in a succession of temporary short-term positions. Thus, most of the agricultural labor force is not subject to being dismissed by an employer as a direct result of a reduction in the amount of labor needed for farmwork. The farmworker, being his own boss, is free to stay on in agriculture as long as he cares to, regardless of whether there is an overall surplus of farmworkers or not. In fact, it is likely that farmers and farmworkers will stay in agriculture during a period of declining labor needs *until* there is a substantial labor surplus because only then will their earnings fall and a change begin to appear attractive. Thus, to some extent, low incomes to farmers and farm laborers must precede any reduction in farm employment. As a result, all farmworkers, both those who are needed and those who are not needed, receive low incomes during a downward adjustment in the farm labor force. If employment was organized more along the lines common to other industries, it would be possible to reduce employment without decreasing the incomes of all workers.

Some farmers and farmworkers have stayed on in agriculture even though their earnings are now at a disastrously low level. In 1962, 22 percent of farm operator families had net incomes of less than $2,000.[17] In 1964, more than 1.5 million farms, 44 percent of the total number, had gross sales of less than $2,500. Fortunately, the operators of many of these inadequate or nominal farms had off-farm or retirement income to supplement their meager farm earnings. Still, estimates based on 1959 census data show that approximately 6 million rural farm people and 10 million rural nonfarm people had incomes below $3,000—the level accepted as an indication of poverty.[18]

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[13] Edwin G. Strand and Earl O. Heady, "Productivity of Resources Used on Commercial Farms," USDA Technical Bulletin, No. 1128, 1955.

[14] D. Gale Johnson, "Labor Mobility and Agricultural Adjustment," *Agricultural Adjustment Problems in a Growing Economy*, Iowa State University Press, Ames, 1958, pp. 163–172.

[15] Luther G. Tweeten, "The Income Structure of Farms by Economic Class," *Journal of Farm Economics*, Volume 47, Number 2, May 1965, pp. 207–221.

[16] Gladys K. Bowles and Walter K. Sellers, "The Hired Farm Working Force of 1963," U.S. Department of Agriculture, Agricultural Economic Report No. 76, 1965.

In reality, farmers and farmworkers having very low incomes are economically unemployed or underemployed regardless of whether they are physically at work for most of the year or not. The total number of rural farm residents that were economically unemployed was calculated to be 1,477,000 persons in 1959—more than 37 percent of the total rural farm labor force at that time.[19] The percentage of unemployment or its equivalent changed but little from 1949 to 1959 although the absolute number decreased due to a decrease in the size of the farmwork force.

Unemployed and underemployed farmers and farmworkers are found in many cases to be handicapped, illiterate, or aged, all of which limits their capacity for work. Almost without exception, the farmers with very low incomes have only a meager supply of land and capital to combine with their labor. As a result, they revert to working only part of the time or use antiquated, labor-intensive methods that give correspondingly low returns.

The adjustments now taking place in agriculture are working to correct the labor surpluses and low income problems. From 1939 to 1959, the number of farms with less than $2,500 gross sales declined by one-half.[20] Most of the decline occurred in the group of farms having no appreciable nonfarm income and a farm business so small that labor earnings averaged less than $500 in 1960. The number of farms in this category declined from 2.2 million in 1939 to 0.2 million in 1964, removing some of the most serious cases of poverty and underemployment in agriculture.

In the past 6 years, a definite downtrend has been registered in the number of farms having gross sales of more than $2,500 but less than $10,000. The total number of farms in this category had dropped only 20 percent in 20 years from 1,686,000 in 1939 to 1,347,000 in 1959. From 1959 to 1964, they decreased to 940,000. Many of the farms in this group are beyond the poverty level on the basis of total income from realized net farm income, off-farm income and nonmoney income; however, labor earnings per worker are still low, indicating a need for recombination and increases in size.

Mobility of Farm Workers

If reductions in the farm labor force had occurred at an even more rapid pace, some of the worst income problems might have been averted. However, there are limits to the numbers of people that can be transferred in a short period of time and in a somewhat orderly fashion from one industry, occupation, or location to another. Unfortunately, several factors in the agricultural situation reduce the possibilities for rapid transfer of workers to other jobs.

One hindrance to movement from agricultural to nonagricultural employment is the relative isolation of agriculture and scarcity of other industries in many rural farming areas. Thus, a change to nonfarm employment often requires a change of residence as well as occupation. The farmer or farmworker faced with this prospect may feel, with some justification, that he will be at a disadvantage in competing with city residents for a new job in strange surroundings. Also, a job change that requires that home ties be broken will be made less quickly than would a change in the same locality.

One of the ironies of the labor adjustment has been the frequent decline of local nonfarm employment opportunities along with the decline in need for farm labor. As the number of farms and the farm population have decreased, so has the business of local trades and services. Thus, the one possibility in many communities for local nonfarm employment has often become, instead, a net supplier of labor.

Another hindrance is the lack of transferability of farm skills to nonfarm jobs. A farmer tends to develop skills in a broad range of tasks ranging from hand labor through machine operation and maintenance up to management. However, few, if any, of the skills are exactly those needed by nonfarm employers, nor are they as highly developed as the skills of an industrial employee with concentrated training and experience. Thus, the farmer or farmworker seeking nonagricultural employment is apt to find that only a small part of his experience and acquired skill is directly transferable. As a result, many farm to nonfarm migrants find employment in the unskilled occupations where earnings, job security, and job satisfaction are likely to be low.

Lack of education has also hindered many transfers from farm employment. Farmers and farmworkers have typically completed fewer years of school than their industrial counterparts in any occupation except laborers. And education in rural areas is still running somewhat below the standards for the rest of the economy.

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[17] *Survey of Current Business*, April 1964, p. 7.

[18] Alan R. Bird, "Poverty in Rural Areas of the United States," U.S. Department of Agriculture, Agricultural Economic Report No. 63. 1964, p. 3.

[19] Bird, *op. cit.*, p. 12.

[20] Radoje Nikolitch, "The Expanding and the Contracting Sectors of American Agriculture," USDA Agricultural Economic Report No. 74, 1965.

The group least affected by these hindrances to mobility are the farm youth. Young people just entering the labor force tend to have fewer ties to the local community, fewer educational inadequacies, and more adaptability to developing skills needed in industry. They have moved in large numbers to seek nonfarm jobs in urban areas.

In 1950, nearly 60 percent of the farm-nonfarm migrants were under 25 years of age.[21] Thirty-three percent of the farm-nonfarm migrants were between 14 and 24 years of age, the period when young people are entering the labor force and making early adjustments prior to settling down in a permanent job.

These young people and others migrating from farm to nonfarm areas have tended to show a disappointingly large concentration in the lower income, semiskilled, and unskilled positions. Several studies have indicated a tendency for farm migrants to concentrate in the categories of laborers, operatives, and craftsmen and foremen in higher percentages than urban migrants or urban residents who did not migrate.

The high rates of outmigration by young people from farming areas are reflected in very low rates of entry of young people into farming. An analysis of entries and exits of farmers in various age groups by Clawson [22] reveals very clearly the reduction in entry of young people to farming. In 1950, there were 164,000 farm operators 15–24 years of age. By 1960, the same age group, now 25–34 years of age, had increased to 403,000. In contrast, there were 419,000 farmers 15–24 in 1910 and 1,333,000 who were 25–34 in 1920. Normally, a few more from a given age group enter farming during the period of time when they are 35–44 years of age; from then on, the numbers tend to taper off due to death, disability, retirement, and change of occupation. It is quite clear that the farm youths who reached 15–24 years of age in 1950 are entering farming in about one-third the numbers of the counterpart group that reached ages of 15–24 in 1910. By 1960, the exodus was even more apparent—there were only 62,000 farm operators between 15 and 24 years of age. This is only about one-seventh the number of young farm operators entering in 1910 and only slightly over one-third of the 1950 number. The total number of young farm operators under 35 years of age in 1960 was only 464,000. In 1950, there had been nearly twice as many young farmers and in 1910, almost four times as many. Clawson concludes, "Men do not withdraw from farming even under considerable provocation; they simply refuse to enter it when prospects are not good. This is further evidence that the salvage value is low for the farmer whose education, experience, and dedication are to agriculture. Having made his choice and having spent a major part of his adult life as a farmer, he is reluctant or unable to leave even in the face of low returns. On the other hand, not yet having chosen or begun a life occupation with the prospect of hard work and low income staring him in the face, he [the young person who might have become a farmer] leaves the farm for employment elsewhere." [23]

The present age distribution of farmers favors a continued reduction in numbers of farmers by holding entries low and letting natural exits through death and retirement bring about the adjustment in numbers. In 1959, there were 1.4 million farmers 55 years of age or older, not significantly lower than the 1.6 million farmers who were 55 or over in 1949. On the basis of past experience, we can expect a decline of nearly 1 million from this group during the 1960's. And in 1970, there will still be almost as many farmers reaching these ages of heaviest exit. Thus, for some time to come, the potential for decreases in the number of farmers will continue at almost the same absolute level as in the recent past. The extent to which this decrease in farm numbers will be realized depends upon two factors, the extent to which further adjustments in farm numbers are needed and the existence of nonfarm job opportunities for rural youth and young adults.

Every indicator and projection seems to point to a need for substantial further reductions in the number of farms and the size of the total farm labor force. One indication of the reduction needed can be obtained by calculating the number of farms that would be left after reorganizing the land and capital resources of undersized farms into more adequate units. Brewster [24] has estimated that 1.6 million commercial farms having sales of less than $10,000 in 1959 could be reorganized into 0.66 million farms having sales of $10,000. Preliminary 1964 data indicate that about 35 percent of the small group had already been consolidated by that time but the growth in numbers of larger farms was less than Brewster's estimates. Completion of this adjustment alone would lead to a decrease of 800,000 farms.

Another approach to estimating the potential for reducing farm employment is to calculate the output per man on efficiently organized farms and determine the number of workers needed on that basis to produce current farm output. Morris and Kadlec [25] estimated that output per full-time man in agriculture was more than twice the present output per average worker. On "superior Midwestern farms," output per worker was three times as great as that calculated output per full-time man. Thus, it is conceivable that eliminating partial unemployment among farmworkers and achieving presently attainable levels of productivity would make it possible to supply our present markets while using only one-sixth as much labor. An increase of that magnitude in output per man would imply a reduction in farm employment from the current level of 6.1 million (as reported by AMS) down to approximately 1 million full-time farmworkers.

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[21] Larry Sjaastad, "Occupational Structure and Migrational Patterns," in *Labor Mobility and Population in Agriculture,* Iowa State University Press, Ames, Iowa, 1961, p. 19.

[22] Marion Clawson, "Aging Farmers and Agricultural Policy," *Journal of Farm Economics,* February 1963, pp. 13–30.

[23] Clawson, *op. cit.,* p. 27.

[24] John M. Brewster, "The Changing Organization of American Agriculture," paper presented to the Agricultural Committee of the National Planning Association, Oct. 29, 1961, p. 15.

[25] W. H. M. Morris and John E. Kadlec, "An Evaluation and Projection of Output per Man in Agriculture," *Journal of Farm Economics,* December 1963, pp. 1007–11.

A review of the labor-use situation in major farm enterprises indicates not only the possibility but also the desirability of further reductions in the amount of labor used. Four major farm enterprises—tobacco, vegetables, cotton, and milk cows—had such high rates of labor use that gross returns per hour of production labor were obviously too low to allow adequate returns (table 5). The worst situation was in the tobacco enterprise, where gross returns in 1963 were only $2.30 per hour of labor used. Even if the entire value of production had gone to labor, it would not have have been possible to return the workers an amount equal to the factory wage rate of $2.36 per hour. Of course, much of the gross return to these enterprises actually went to cover out-of-pocket costs and give a return on capital, so the wages paid and labor return to farm operators were necessarily quite low. The only feasible way of correcting the low labor returns in those enterprises is to reduce the labor input and thereby raise the value of output per hour of labor used.

TABLE 5. MAN-HOURS OF LABOR USED FOR FARMWORK, VALUE OF PRODUCTION, AND PRODUCTION PER MAN-HOUR, BY GROUPS OF ENTERPRISES, 1963

	In millions		Production per man-hour
	Man-hours	Value of production	
Crops:			
Tobacco	589	$1,353	$2.30
Fruits and nuts	548	1,464	2.67
Vegetables	402	1,206	3.00
Cotton	645	2,462	3.82
Sugar crops	93	444	4.77
Hay and forage	476	[1] 2,738	5.75
Feed grains	577	6,011	10.45
Oil crops	183	2,160	11.80
Food grains	167	2,505	15.00
All crops [2]	4,134	21,378	5.17
Livestock:			
Milk cows	1,485	[3] 5,144	3.46
Poultry	488	3,360	6.88
Meat animals	1,307	9,826	7.52
All livestock [2]	3,454	18,470	5.35

[1] Does not include corn silage value nor sorghum silage.
[2] Includes items not listed separately.
[3] Milk only.

SOURCE: *Agricultural Statistics*, 1964.

With several indications of need for further reductions in farm labor force, attention is turned to the possibilities of attracting the more-mobile farmworkers to nonfarm employment. Evidence from past experience clearly indicates that the most essential element to continuous flow of labor from agriculture is a high rate of employment in the nonfarm economy. The Great Depression of the 1930's stands out as a clear example of a period in which high unemployment in the nonfarm economy stopped migration from farms. During 1930–35, annual net migration from farms was only 58,000, less than one-tenth as great as during any other period from 1920 to 1964. Another indication of the effect of unemployment is given by Bishop's[26] finding that the rate of migration from agriculture tended to increase by about 0.6 percent for each 1 percent decrease in the rate of unemployment in the nonfarm economy. This type of response is no different than the response of nonagricultural workers. According to Parnes, "That the amount of voluntary labor mobility varies directly with the extent of employment opportunities is amply substantiated by data on labor turnover. . . . The volume and nature of employment opportunities are of paramount importance in conditioning the extent and incidence of labor mobility."[27] Workers, whether they be farm or nonfarm, are reluctant to leave their present position, poor though it may be, to take a chance in a job market where unemployment is high.

Summary and Conclusions

The development and adoption of output-increasing and laborsaving technologies in agriculture have made it possible to satisfy growing demands for food without increasing the total amount of resources used for agricultural production. Substantial reductions in the amount of labor required in farm production contributed to increased efficiency in agriculture and released workers for expanding industries.

The agricultural labor force was, in many respects, ill prepared to adjust to the decrease in labor needs. Many farmers and farmworkers who "gradually lost their job" stayed on in agriculture in a semiunemployed status because their opportunities outside of agriculture also seemed very bleak. Operators of "inadequate farms" are the locus of much of the poverty in agriculture. Their position is comparable to the chronically unemployed worker in industry; however, assistance programs have generally not met their needs. Appropriate policies should stress welfare needs and retraining to provide for reemployment.

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[26] C. E. Bishop, "Economic Aspects of Changes in Farm Labor Force," in *Labor Mobility and Population in Agriculture, op. cit.*

[27] Parnes, *op. cit.*, p. 142

It appears that there will continue to be reductions for some time to come in the number of farms and the amount of labor required in agriculture. A decrease of 50 percent in the next 20 years is not at all outside the realm of possibility. The enterprises where the reductions are most likely to occur are those presently having high labor inputs and low output per man-hour.

The adjustments that have occurred in the farm labor force have come about largely through a sharp decrease in number of entrants and natural attrition among the older workers. The prospects appear to be good for continuing to reduce the level of farm employment by this approach for the next 15 to 20 years. Policies that encourage retirement at an early age and assure adequate nonfarm job opportunities for farm youth would facilitate this process.

A faster rate of reduction in farm employment would be highly desirable, but few farmers in the middle and older age groups have found their opportunities in nonfarm employment to be any better than on the farm. If farmers and farmworkers had been better educated and experienced or trained in skills desired by nonfarm employers, undoubtedly more would have found nonfarm employment. For many of these older workers it is too late to remedy past errors of insufficient education and dependence on highly vulnerable specialized skills. The lesson for the future is clearly that education should not be underrated even though it may seem, at the time, to be of little practical value.

TECHNOLOGICAL CHANGE IN BANKING

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Technological Change in Banking

Introduction[1]

A quick comparison of one's canceled checks for the past month with those of a few years ago would reveal that technological change has been extraordinarily rapid in the banking industry during that time.[2] The equipment that is the vehicle for this technological change has naturally caused quite a stir in the banking world. One banker was even moved to say it had "sex appeal."[3] Because the pace of change has been so fast and the change itself so extensive, banking makes an excellent case study of an industry adjusting to technological change.

This study first examines the nature and extent of the change which took place, and then deals with the causes underlying the change. Next it looks at the effect of that change in three major areas—the services offered by the industry, the effect or potential effect on the price, output, and efficiency of the industry, and the effect on manpower in the industry. At the end, brief note is taken of existing and potential legal barriers to technological change in the industry.

I. The Nature and Extent of Technological Change in Banking

It would be well at the outset to describe the new equipment being used in banking. At the heart of the new methods is a changeover to electronic data processing (EDP). Two of the most important machines in this changeover are reader-sorters, which read and sort documents (especially checks), transmitting data via a computer to be recorded on tape, and the computer itself, which processes the information fed it by the reader-sorter. These two machines supplement or, in many cases, eliminate entirely the conventional machines and processes for sorting checks, balancing accounts, preparing overdrafts, and computing average balances and service charges.

A prerequisite to the introduction of EDP was an agreement by banks in 1959 on a standard form of magnetic ink character recognition (MICR). MICR involves encoding documents with an ink containing iron oxide, which can be magnetized, so that a machine can read the ink and sort the documents. For example, checks may be encoded with the routing and transit number of the bank, the checking account number of the customer, and/or the amount of the check. This greatly facilitates the handling of such documents, especially when large quantities of checks and other documents are being handled. High-speed sorters can process more than 1,560 checks per minute. MICR symbols are now used almost universally in the United States and in some foreign countries. A recent Federal Reserve Board survey showed that 87 percent of the checks cleared through the Federal Reserve System are encoded, and that 99.9 percent of the banks in the country are encoding some of their checks.[4]

Another innovation is the electronic bookkeeping machine, or "tronics," which has taken the place of many of the conventional posting machines. By simplifying the bookkeeping function, the electronic bookkeeping machine reduces the possibility of error and increases the speed of posting transactions. One large bank reports its posting errors have decreased two-thirds as a result.[5]

The use of EDP machines spread with great speed, as can be seen in table 1. And in the coming decade, computers will become even more widespread. Table 2 shows expected usage in 1970 and 1975.

Responses to the survey may well have been made on the assumption that the price of computers and other equipment would remain constant. Since prices have fallen and probably will fall further, these results may understate the spread of technological change in the next decade.[6]

It is clear from these statistics that the larger banks were the leaders in introducing the new

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[1] The author acknowledges the helpful comments and criticisms of John Dunlop and Frank Sloan of Harvard University, David Ness of MIT, Dale Reistad of the American Bankers Association, Garth Mangum of the National Commission on Technology, Automation, and Economic Progress, and R. Thayne Robson of the President's Committee on Manpower. Any errors or inaccuracies which remain are, needless to say, his own responsibility.

[2] Not wishing to become embroiled in a discussion of how one quantitatively measures the extent of change, the author appeals to the qualitative changes in production techniques described below as justification for this statement.

[3] *Business Week,* Oct. 17, 1964, p. 156.

[4] American Bankers Association, *Proceedings of the 1964 Conference on Automation,* p. 28. Hereafter cited as *1964 Proceedings.*

[5] Department of Automation and Marketing Research, American Bankers Association, *Automation and the Small Bank,* New York: American Bankers Association, 1964, p. 19. Hereafter cited as *Automation and the Small Bank.*

[6] Reference to falling equipment prices has been made by Dale L. Reistad in two places. See American Bankers Association, *Automation and the Small Bank, op. cit.,* p. 10, and Address Before the Departmental Conference of the American Institute of Banking, New Orleans, June 1, 1965, mimeo.

TABLE 1. BANK USE OF EDP MACHINES

Size of bank (deposits in millions)	Banks using computers (percent)		
	1960[1]	1962[2]	1964[1]
Over $500	27.8	96.7	92.2
$100–$500	7.8	70.7	85.6
$50–$99	1.0	33.9	52.6
$10–$49	----------	[3] 17.4	11.6
Under $10	----------	----------	1.3

[1] Dale L. Reistad, director of Automation and Marketing Research of the American Bankers Association, New York, N.Y., "Trends in Banking Automation," in American Bankers Association, *Proceedings of the 1963 National Automation Conference*, p. 16. Hereafter referred to as *1963 Proceedings*. The 1964 figures are banks which expected in late 1963 to be using computers by the end of 1964.

[2] James B. Eckert and Robert R. Wyand II, "Automation at Commercial Banks," *Federal Reserve Bulletin*, November 1962, p. 1409. The apparent decrease in computer usage from 1962–64 in the over $500 million category must be attributed to sampling error or to the effect of mergers of large banks using computers during this time.

[3] $25–$50 million only.

TABLE 2. PROJECTED BANK USE OF EDP MACHINES

Size of bank (deposits in millions)	Banks using computers (percent)	
	1970[1]	1975[1]
Over $500	100.0	100.0
$100–$500	98.8	100.0
$50–$99	84.6	90.5
$10–$49	59.0	67.8
Under $10	19.3	37.9

[1] 1963 *Proceedings*.

equipment. Often it is said that this was due to the "high initial cost" of the equipment or to "the risks involved in moving into relatively untried fields."[7] Both these notions can be clarified.

"High initial cost" essentially means that banks had to have a certain volume of business to justify installation of EDP. But to know if this was the case one must know how the costs of processing data using conventional machines and using EDP varied with volume. No statistics bearing directly on this matter were found, but the ratio of total current operating expenses to loans and investment in 1959 will give an idea of the costs using conventional machines. Interest on time and savings deposits is deducted from expenses since it is a relatively large item which, on its face, would seem to have little to do with data processing costs. Table 3 shows that unit costs do not decline very much as size increases for banks in the $2–$500-million range.[8]

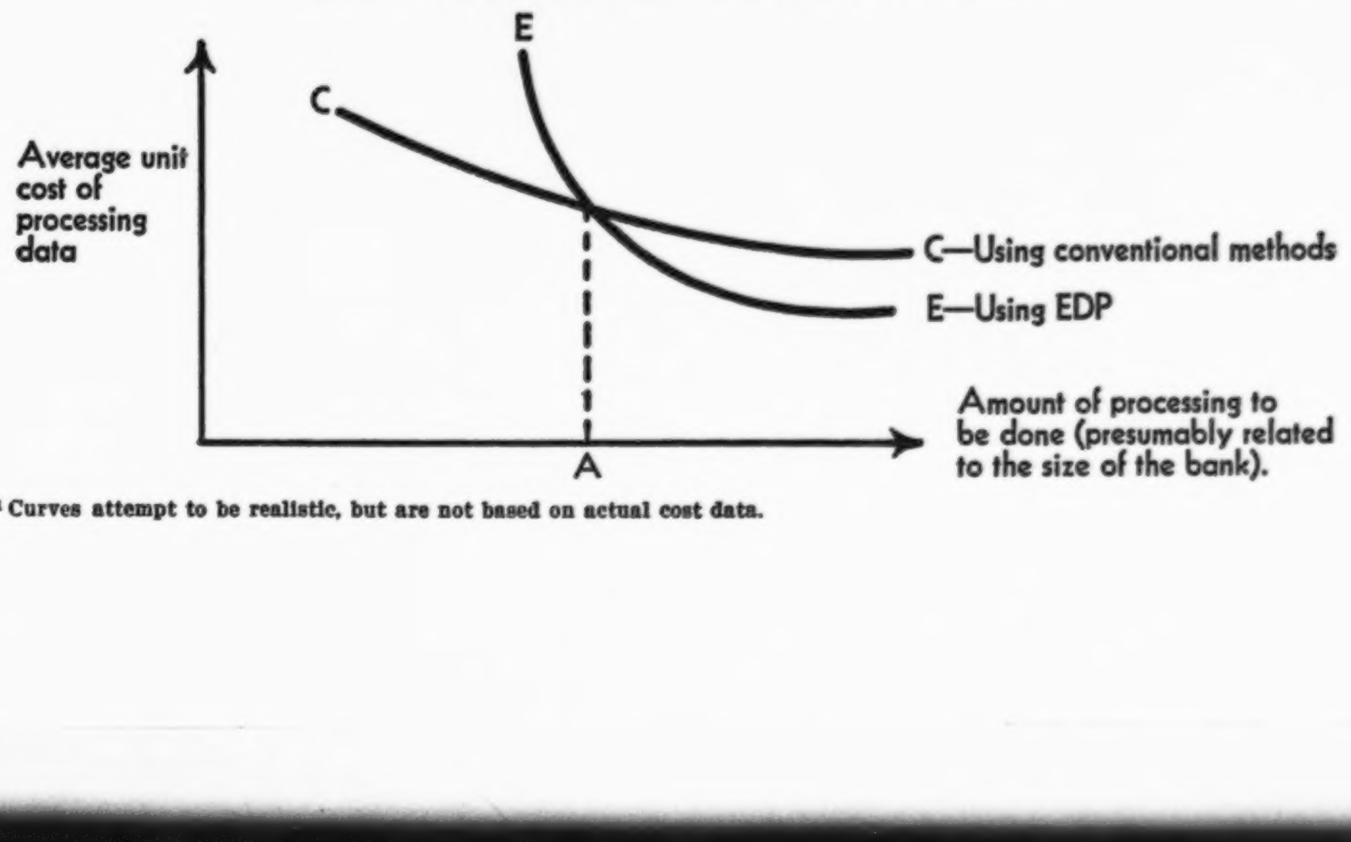
What about costs using EDP? In the early years of EDP, small-capacity equipment was not on the market, and on the large-capacity equipment that was available, unit costs fell as capacity was approached.[9]

TABLE 3. RATIO OF TOTAL OPERATING EXPENSES TO SIZE OF BANK, 1959

Size of bank (deposits in millions)	Total current expenses minus interest on time and savings deposits/loans and investments
Under $1	3.17
$1–$2	2.85
$2–$5	2.69
$5–$10	2.65
$10–$25	2.72
$25–$50	2.75
$50–$100	2.62
$100–$500	2.74
Over $500	2.35

This means that there was some size bank where unit costs of processing data using EDP equaled those using conventional equipment, and that for banks larger than that size it was profitable to install EDP.[10] (See figure 1.)

FIGURE 1. *Variation of Data Processing Costs With Volume*[1]



[1] Curves attempt to be realistic, but are not based on actual cost data.

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[7] See, for example, Eckert and Wyand, *op. cit.*, p. 1409.

[8] Paul M. Horvitz, "Economies of Scale in Banking," in Commission on Money and Credit. *Private Financial Institutions*, Englewood Cliffs, N.J.: Prentice-Hall, 1963, pp. 15, 19.

[9] That computers "freeze" costs and thus should be adopted is a common theme in the trade literature. See, for example, *1963 Proceedings*, op. cit., pp. 15, 64. Freezing total costs is equivalent to decreasing unit costs as volume rises.

[10] The assumption has been made that for the first few items unit costs using EDP are greater than those using conventional methods. Given the reference to "high initial cost," this seems justified.

For banks greater than size A, it was profitable to introduce EDP. Over time, as cost of EDP equipment fell, EE, and hence A, shifted to the left. The appearance of small-capacity equipment lowered unit costs of small volumes and caused EE to flatten out, moving A farther to the left. Also, banks grew, moving the amount of data processing they had to do to the right.[11] Thus, as time passed, smaller banks began to adopt EDP.

That "the risks involved in moving into relatively untried fields" is a deterrent to small banks taking the lead in investing also deserves a further explanation. Risk applies to situations with uncertain outcomes. In general, the wider the range of possible outcomes, the higher the risk. Of course, there is always some possibility of a loss, and it is quite likely that any given loss means more (or is more critical) to a small than to a large bank, since that loss represents a larger proportion of the small bank's assets. If a corresponding size gain does not mean more to a small bank (and so would not offset the loss), the small bank will be more averse to risk than the large bank. If a given amount of risk is associated with the investment in EDP, the large bank would be more willing than the small to assume it. After large banks pioneer EDP, risk is reduced, and small banks will also invest, if they still expect a profit.[12]

Large banks may also have been the leaders because of their more aggressive management, particularly over small banks outside large cities, or large banks may simply have had the personnel (e.g., a corporate development group, or the like) needed to introduce EDP.

To sum up, banks have begun to use electronic data processing equipment extensively. The large banks were the innovators, partly because benefits at the time EDP was first introduced accrued only after a certain volume of business was reached; the large banks were better able to bear initial investment risks; their management may have been more aggressive; and only large banks may have had the staff necessary to make such an innovation.

II. Causes of Technological Change in the Banking Industry

Not very surprisingly, cost and revenue factors are fundamental to any explanation of why banks adopted EDP. To freeze or reduce operating costs was the most important factor in the decision of 314 banks to automate, according to a 1963 survey. The results of that survey are shown in table 4:

TABLE 4. EVALUATION OF FACTORS IN AUTOMATION DECISION BY 314 BANKS, IN PERCENT

Factor	Major	Minor	None
Freeze or reduce operating costs	82	15	3
Improve internal systems	71	24	5
Improve management reports	50	40	10
Enable bank to offer additional services	43	38	19
Increase flexibility in handling business	42	43	15
Tighten audit control	36	47	17
Meet competition	32	38	30

SOURCE: *Banking*, November 1964, p. 108.

A closer examination of some of these categories will shed light not only on why EDP was adopted, but why its spread was so rapid.

The most striking aspect of banking throughout the past decade has been its growth; many have pointed to this expansion and expected further growth as the chief causes of bank automation. It is certainly true that virtually all measures of bank activity have shown large increases in the past decade. Although the number of banks has been reasonably constant, the number of bank offices rose 37 percent in the decade, and the civilian population per bank office fell each year.[13] The number of checks processed by the Federal Reserve System rose 63 percent from 1955 to 1964.[14] The number of demand deposit accounts increased 10 percent from 1955 to 1960, the date of the latest survey of such accounts.[15] Some of this increase, no doubt, reflects the greater use of special checking accounts which require no minimum balance. Furthermore, there was an 18-percent increase in the average number of checks written per account from 1955 to 1960.[16] As would be expected, the pressure of this demand increase showed up in price increases. Service charges per $100 of demand deposits rose 84 percent from 1955 to 1964, and 48 percent when deflated by the service price deflator of GNP.[17] Employment in the industry rose from 549,300 in 1955 to 761,400 in 1964, an increase of 39 percent.[18] (See table 5.)

Not only did bankers face a large increase in demand, but they had (and have) every reason to expect this trend to continue. In the 1949–60 period, there was a close relationship between the population 21 years old and over and the number of demand deposit accounts; there was also a steady upward trend in the average number of

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[11] Of course, the curves did not look exactly like this for all banks. If they did, assuming cost minimization, all banks larger than size A would automate and none smaller would.

[12] These ideas are made rigorous in the appendix.

[13] From annual reports of the Federal Deposit Insurance Corporation (FDIC).

[14] From annual reports of the Federal Reserve Board. Data are exclusive of U.S. Government checks and postal money orders. Federal Reserve clearances represent slightly more than one-fourth of all checks drawn on commercial bank accounts.

[15] Data from the *Federal Reserve Bulletin*, April 1961, pp. 405–408, and from annual reports of the FDIC.

[16] Calculated by dividing the number of accounts into the number of checks processed by the Federal Reserve System.

[17] Data from annual reports of the FDIC, price deflator from the *Economic Report of the President*.

[18] Annual reports of the FDIC.

TABLE 5. MEASURES OF BANK ACTIVITY, 1964

Year	Number of banking offices	Number of checks processed by Federal Reserve System (millions)	Demand deposit accounts (millions)	Average number of checks/account	Service charges per $100 of demand deposits	Service charges per $100 of demand deposits deflated by service price deflator	Employment in banking (thousands)
1955	21,676	2,643	52.1	50.7	$0.25	$0.25	549.3
1956	22,315	2,823	N.A.	N.A.	.28	.27	578.7
1957	22,907	2,975	52.2	57.0	.32	.30	602.9
1958	23,553	3,085	53.7	57.4	.34	.31	616.8
1959	24,242	3,258	54.4	59.9	.36	.32	640.5
1960	25,105	3,419	57.1	59.9	.39	.34	672.5
1961	26,002	3,631	N.A.	N.A.	.43	.37	693.5
1962	27,029	3,873	N.A.	N.A.	.44	.37	714.0
1963	28,369	4,069	N.A.	N.A.	.46	.38	740.4
1964	29,727	4,319	N.A.	N.A.	.46	.37	761.4

N.A.—Not available.

checks written per account.[19] By using those relationships to project to 1975, the number of demand deposit accounts can be expected to increase at an annual rate of 3.4 percent (from 1965-75) (see table 6).[20]

TABLE 6. PROJECTIONS OF BANK ACTIVITY

Year	Population 21 years and over [1] (millions)	Demand deposit accounts (millions)	Average number of checks per account cleared through Federal Reserve System	Total number checks processed by banking system [2] (billions)
1965	114.4	66	67	17
1970	123.5	78	74	22
1975	134.1	92	81	29

[1] Based on Bureau of the Census projections.
[2] Calculated on the assumption that the proportion of checks cleared through the Federal Reserve System remains 26 percent.

What is important, though, is that the bankers themselves actually expected these trends to continue, since they, after all, were making the investment in EDP. The president of a large bank wrote in 1963:

> We have seen our work volumes increase at an alarming pace, and our costs rise in proportion. Automation was looked to as the great leveler—a means to handle increased workloads without proportionate cost increases; and a means to insure that the banking system did not fall apart merely by not being able to obtain sufficient human hands to perform its work manually. As we look at the initial results of this first phase, we can be proud of our accomplishments. . . . We are not now likely to be engulfed by paperwork volumes.[21]

The same bank's vice president said 1 year later:

> . . . the computer is not our enemy, it is our saviour. Without computers some banks simply would not be able to function today, and the rest of the industry would soon be so engulfed by paperwork we would have to curtail seriously the scope of our operations.[22]

Another bank says that "its main reason for interest in EDP was a vision of a 'flood of uncontrolled paper' as matters were developing"[23]

The counsel for the Connecticut Bankers Association, in testifying before the House Banking and Currency Committee, stated that:

> A survey . . . indicates that throughout the entire country banks handle no less than 50 million items every normal business day, and even more during peak periods. This tremendous volume must move with great speed and efficiency. . . . Banks have been forced more and more to turn to electronic data processing equipment to help cope with this recordkeeping and document handling volume.[24]

It would be easy to conclude from these statistics and statements that the banking system faced a workload of such immense proportions that it had no alternative but to adopt EDP. The image of a deluge of paper is readily conjured up, but the conclusion that this by itself forced automation onto the industry is based on the tacit assumption that the increased workload either could not be processed on conventional machines or that the cost of doing so would not have been economically feasible.

However, it does not seem that costs would have risen enough to make conventional methods economically impractical. In fact, unit costs could conceivably fall. The figures cited above as an approximation of 1959 data processing costs showed roughly constant unit costs up to the $500-million size and a decline above that size (see table 3). This indicates that using conventional methods there would have been no rise in marginal costs (cost per unit of the additional volume) associated with an increased volume, and that there may even have been a decline.

A slightly different argument is that banks simply could not obtain the personnel needed to process the data at the wages being paid,[25] and that without EDP their position would be analogous to that of the telephone company without dial equipment. (It is said that if there were no dial equipment, every woman in the country would have to be a telephone operator to handle the current volume of calls.)

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[19] Rose Wiener, "Changing Manpower Requirements in Banking," *Monthly Labor Review*, September 1962, p. 991.
[20] *Ibid.*, p. 992.
[21] John A. Mayer, president, Mellon National Bank and Trust Co., Pittsburgh, *1963 Proceedings, op. cit.*, pp. 82–83.
[22] Richard W. Sherman, vice president, Mellon National Bank and Trust Co., Pittsburgh, *1964 Proceedings, op. cit.*, p. 185.
[23] Stanford Research Institute, *Management Decisions to Automate*, prepared for the U.S. Department of Labor, Office of Manpower, Automation, and Training, p. 18.
[24] Harold E. Read, Jr., in *National Bank Legislation*, Hearings before Subcommittee No. 1 of the Committee on Banking and Currency, House of Representatives, July 19, 1962, p. 54.

This argument is hard to judge; certainly wages would have had to have risen after some point if more personnel were to be obtained. But it is unclear exactly where that point lay, and how near banks were to it. Also, local labor markets (the relevant markets for this kind of personnel) undoubtedly differ in the relative availability of such personnel.

If, then, it was technologically and economically feasible to process the increased workload with conventional methods, the only possible explanation for the adoption of EDP is simply that it was a cost-saving innovation, at least for banks above a certain size. Then the recent sharp increase in volume would only be relevant as a cause of automation insofar as it took some individual banks to the point where EDP became profitable. For banks above that level originally, EDP would have been introduced whether or not business increased.

There are a number of reasons, both theoretical and empirical, to believe that EDP was a cost-saving innovation. In the first place, assuming cost minimization, if the investment is not expected to save the bank money starting with its installation, it will not be made and the bank will wait, unless for some strange reason the bank expects the investment opportunity to disappear.[26] This disposes of the argument that banks foresaw EDP as a future necessity and hence automated. A future necessity which costs more in the present than in the future (because the bank ties up funds, suffers depreciation, and the expected price charge for the equipment is probably negative) and does not save any money in the present is bought in the future.

Empirically, given the numerous internal applications of EDP, it would be strange if costs were not lowered, even at present levels of operation. Both ABA and Federal Reserve Board surveys have shown banks applying EDP to many areas (see table 7).

In all the areas listed in table 7, less manpower is required with EDP. In addition, turnover problems are not of the magnitude they were, which can result in a sizable cost reduction.[27] One bank, whose turnover was the major factor in its decision to automate, estimated turnover cost could be as high as $500 to $1,000 per person.[28] EDP equipment also saves the bank money by taking up less workspace.[29] Thus, EDP should lower costs independently of a demand increase. The rise in demand can only increase the amount of the savings.

Case study evidence generally confirms that EDP is a cost-saving innovation. For example, one large California bank figures that its bookkeeping costs have been reduced by something like $1 million per year at current levels of activity, although this assumes that much of the early study and programing costs are already written off.[30] A case study of a cooperative data processing center formed by several small banks shows that the system should pay itself off in 5 years and and return its cost every 4 years after that.[31] Although these examples cannot be taken as proof that EDP always reduces cost, published cost figures do support the hypothesis that many banks would have automated independently of any large increase in demand, and that the increase in demand only caused additional banks to automate sooner.

The reasonableness of this hypothesis is strengthened by the speed that EDP spread from

TABLE 7.—AREAS TO WHICH EDP EQUIPMENT IS APPLIED

Area	Number of banks in sample	Converted [1]	Being converted [1]	Planning [1]	Low priority [1]	No plans to convert [1]	Other [1]	Automating banks automating service, March 1962 [2] (percent)
Regular checking	327	57	22	20	1			86.8
Special checking	297	66	16	15	1	1	1	80.1
Consumer loans	306	27	12	45	8	3	5	72.0
Savings accounts	313	31	15	32	13	4	5	57.9
Mortgage loans	287	15	7	38	18	14	8	52.6
Personal trust	267	16	8	34	20	12	10	38.5
Corporate trust	253	19	9	28	18	16	12	31.3
Commerical loan	262	6	3	23	27	27	14	32.9

[1] *Banking*, October 1964, pp. 52–53.

[2] Federal Reserve Board Survey of 972 banks in Eckert and Wyand, *op. cit.*, p. 1413.

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[25] This says, in effect, that the supply curve of labor faced by the industry is inelastic.

[26] This statement must be modified to the extent that there are nonrecurring costs associated with the installation of EDP which are not incurred immediately. For example, a bank may take 4 years to automate and incur dislocation costs over those 4 years. For some or all of those years net returns could be negative. The bank can, of course, net out these costs from its stream of returns and proceed to analyze whether it should introduce the project in the usual way. It should also consider if the dislocation and other costs of introducing EDP will change over time.

[27] See the discussion below of the impact of EDP on manpower.

[28] Stanford Research Institute, *op. cit.* pp. A5–6.

[29] *Ibid.*, p. 16.

[30] Stanford Research Institute, *op. cit.*, p. A8.

[31] *Automation and the Small Bank*, *op. cit.*, p. 29.

larger to smaller banks. This seems to indicate that point A in figure 1 was moving to the left much faster than demand was pulling banks to the right of point A. If demand has been pulling, bank size would have increased, and the statistics would not show greater usage among small banks. Although this may seem obvious upon reflection, the popular view places a great deal of emphasis upon the rapidly mounting volume of activity as a cause of bank automation, and not upon its cost-saving features.[32]

Competitive pressures as well as falling equipment prices help explain the speed of the banking industry in embracing the new equipment. As one report stated:

> One of the most independent bankers recently planned to join with a group of banks in an automation venture. Although he was opposed to the direction banks were headed in the new automation services race, he could not fight it and therefore had to prepare his bank for the new competition.[33]

Another banker said:

> Should small banks be concerned about automation? I think we must . . . . *Automation is creating new forms of competitive pressure* . . . . Automation will be necessary to stay alive, for to stand still in today's changing world of banking is to fall behind and run the risk of never being able to catch up.[34]

Of course, factors other than those operating on the supply side are also present. One is the unquantifiable effect the installation of EDP has upon the bank's image, the magnitude of which depends to a large extent upon whether competing banks have adopted EDP already or not.

Another very important factor inducing automation is the multitude of possibilities the computer opens for increasing bank revenue since better management is possible with the computer as an aid. Service charge income tends to rise, since central management can keep better control of service charge waivers by branch managers. Also, there is no monthly lag in computing service charges so that people closing accounts cannot evade the last month's charge. One bank found its annual service fee income up 15 percent and another bank found its annual service fee income up 11 percent after installing EDP.[35] With a computer, management can conduct its own market research and analyze various characteristics of actual or potential depositors. Should it find itself underrepresented in a particular area, it can tailor an advertising campaign to remedy that weakness.[36] The computer also enables management to judge more accurately requests for credit, make credit policy uniform, and ease or tighten credit policy to the desired degree.[37]

New services also increase incomes; they, however, represent the impact the computer has had upon the product of the industry.

III. The Impact of EDP on the Industry's Product

The increased sophistication of the computer and computer techniques has made it possible for banks to offer a vast array of new automated customer services, and, for the most part, banks have enthusiastically done so. Unfortunately, for some, the experience has been somewhat sobering. One prominent member of the banking fraternity estimated that "computer hysteria" cost the banking industry "at least in the tens of millions of dollars and may well have reached $100 million proportions." [38] The traditional stereotype of the banker is certainly at odds with this apparent show of entrepreneurial spirit. Why have bankers been so eager to provide these services, especially when there was a large degree of uncertainty associated with profitability? [39]

One motive certainly had to be the possibility of profit. A management consultant has estimated that "consumer services could make a profit contribution through a net fee income of at least 10 percent to 15 percent of the bank's net operating earnings, in addition to providing new business values and helping to retain balances." [40] Management may also have been willing to take a loss at the moment to gain customers with the expectation that the service would become profitable.

Yet another, somewhat more subtle, factor may be at work. Banks cannot compete for demand deposits by paying interest on them; they do not compete for loans on the basis of price (because of the prime rate convention), and they usually do not compete on the basis of service fees.[41] Rather they prefer to compete through the provision of unique or semiunique services.[42] One reason is that a service may be hard to copy. It may require special organization or skills; other banks not performing the service may be in the dark about how much it costs; and the gain from creating a totally new service may greatly exceed that of copying one already offered by another bank.

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[32] This is not to deny that the cost differential between EDP and conventional methods will increase with time. But emphasis on this distorts why banks automated now.

[33] *Automation and the Small Bank*, *op. cit.*, p. 8.

[34] William R. Synnott, vice president and treasurer, New Britain Trust Co., New Britain, Conn., *1963 Proceedings*, *op. cit.*, p. 64, emphasis in original.

[35] *1963 Proceedings*, *op. cit.*, p. 81. The bank was the First National Bank of Elkhart, Ind.; Stanford Research Institute, *op. cit.*, pp. A 10, B 8–9.

[36] For an account of one bank's experience in this area, see *1963 Proceedings*, *op. cit.*, p. 187.

[37] *1964 Proceedings*, *op. cit.*, p. 351.

[38] A. R. Zipf, senior vice president, Bank of America, *1964 Proceedings*, *op. cit.*, p. 158.

[39] "All too often, computer systems were installed without even rudimentary thought about their costs, their efficiency, and most important, their applicability to the job that needed to be done." (A. R. Zipf, *ibid.*, p. 158.) "One bank, for instance, whose primary interest was in customer relations, operated a payroll service which it found to be a fruitful source of wearisome headaches. Yet it had no evidence that it gained any customers through this particular service, or that it would have lost any had it not provided the payroll service." (M. B. Basson, Price Waterhouse Principal, pp. 248–249.) *Ibid.*

[40] Neil J. Dean, vice president in charge of management information, systems division, Booz, Allen, and Hamilton, Inc., *ibid.*, p. 83.

[41] "It is uncommon, however, for a bank to cut service charges in order to attract depositors." (Deane Carson and Paul H. Cootner, "The Structure of Competition in Commercial Banking in the United States," in Commission on Money and Credit, *Private Financial Institutions*, Englewood Cliffs, N.J.: Prentice-Hall, 1963, p. 94.) This reflects the belief that the supply of deposits is inelastic to changes in service fees, partially because many depositors have long-established loan relationships.

The availability of a computer which makes it possible for banks to offer a whole host of new, specialized, customer-oriented services could well account for the rapid diffusion of computers through the industry. The remarks of one bank vice president lend support to this idea:

> I sincerely believe that banks do now, and will in the future, benefit immeasurably from offering services via their computers, but only insofar as they specialize . . . [and] avoid offering the standard applications. The competition is vicious, and too often pricing is irresponsible. Important rapport develops through specialization only . . . . Specialize to the extent that you become the most able processor of a given type of work. When you do, you will find that price will become incidental. You will not need a price advantage, once you have earned a reputation for excellence of service and for quality of product.[43]

Another banker advised, "Try not to play 'follow the leader' with other banks in the industry in selecting applications."[44]

A description of some of the new services shows the great variety possible. Under a professional or small business billing service, banks bill patients or customers and keep accounting records for doctors, dentists, lawyers, florists, druggists, and the like. The service usually involves installation of a data transmitter at the place of business which feeds information to the bank's computer.[45] The bank benefits not only from a fee for services rendered but also from the client's account. The latter would be negligible if the bank already had the account, but this is not always the case. One large bank performing professional billing services found that more than 25 percent of the participants were new customers.[46] The billing service is popular with professionals because it gives them accurate and complete records, something they often do not keep on their own or do not have in as usable form.[47] It also eliminates the monthly peak-load billing for the professional's office help.[48] The bank can, in addition, perform the collection function for a fee, and can loan money against accounts receivable.

Billing services are not restricted to professionals or small businessmen. Banks are also processing insurance premiums and utility bills, using another piece of EDP hardware, the optical scanner.[49] The meter card is prepared with little boxes which are blackened with a pencil by the meter reader, allowing them to be read by the scanner and put onto tape.[50] This eliminates key punching of information from meter cards and bill stubs. One bank, "pleased" with its experience with an optical scanner for utility billing, is planning to "utilize it for many applications in the future."[51]

Payroll preparation is also being performed by banks. If a company does not own EDP equipment, the bank can generally make a profit and still charge a fee less than the cost to the company of preparing its own payroll. Since employees must open an account at the bank to receive funds, the bank often gains new deposits.[52] If it did not have the company's account before, the bank receives the benefit of the dormant funds traditional in payroll accounts.[53] Payroll preparation is one of the most popular new services: 24 percent of the automated banks in the ABA survey offered it.[54]

Banks need not restrict their computer services to profitmaking firms; for example, cities and towns, particularly those too small to afford their own computers, can profitably use a bank's computer.[55] Cities, of course, can use some of the services described above, such as payroll preparation. In addition, banks can make available special services, such as keeping assessment rolls and collecting taxes, scheduling classes for school systems, scheduling traffic lights, billing and collecting parking fines, keeping voter registration records, and paying interest on bonds.[56]

A hospital is another nonprofit organization which can make use of bank computer services for patient and third party (insurance) billing, accounts payable, inventory control, and recordkeeping.[57]

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[42] ". . . banks do not hesitate to compete vigorously by offering a desirable customer semiunique and highly personalized services of a nonroutine nature. Indeed, this is the main channel for aggressive competition within the banking industry. The provision of new, unique, and specialized services for which a skilled bank staff is a prerequisite is the banking industry's parallel to product differentiation and product innovation in the manufacturing industry. The motivation is the same: To channel competition into forms which are not immediately self-defeating in the sense of reducing profits throughout the industry while leaving an avenue by which an alert and progressive management may win for itself a genuine if temporary advantage." (Donald R. Hodgman, *Commercial Bank Loan and Investment Policy*, Champaign, Ill.: University of Illinois Bureau of Economics and Business Research, 1963, p. 111). See also Carson and Cootner, *op. cit.*, pp. 92–99.

[43] Joseph A. Gallagher, vice president and treasurer, Industrial Valley Bank and Trust Co., Jenkintown, Pa., *1964 Proceedings, op. cit.*, pp. 188–189.

[44] John E. Westhoff, assistant vice president, Pittsburgh National Bank, Pittsburgh, Pa., in *1963 Proceedings, op. cit.*, p. 147.

[45] For details of one plan, see the photocopy of a Bank of America advertisement in *Legislation To Prohibit Banks From Performing Certain Non-Banking Services*, Hearings before the Subcommittee on Bank Supervision and Insurance of the Committee on Banking and Currency, House of Representatives, Feb. 25 and 26, 1964, inset following p. 152. The data transmitter is installed only if volume warrants it.

[46] Proceedings, *op. cit.*, p. 187. The bank is the Mellon National Bank and Trust Co., Pittsburgh, Pa.

[47] John W. Allen, *et al.*, "Automated Customer Services in Banking—A Critical Evaluation," Manufacturing Topic Report submitted to General Georges F. Doriot, Harvard Business School, April 30, 1965, mimeo (to be published).

[48] *Ibid.*

[49] *1964 Proceedings, op. cit.*, pp. 248, 312.

[50] For a detailed, illustrated account see *ibid.*, pp. 312–315.

[51] *Ibid.*, p. 315. The bank is the Mellon National Bank and Trust Co., Pittsburgh, Pa.

[52] "Often" because the bank generally allows the employee to transfer his funds to another bank without penalty, and a certain percentage of employees may already have accounts at the bank.

[53] *1964 Proceedings, op. cit.*, p. 187.

[54] *Banking*, October 1964, p. 64.

[55] The Harvard study estimates that cities above 400,000 can afford their own computer. See Allen, *et al., op. cit.*

[56] *1964 Proceedings, op. cit.*, p. 248; Allen, *et al., op. cit.*

In the real estate field, a bank can maintain a central file of properties within an area that can be cross-indexed in several different ways—by land type and location, structure type, whether property is for rent or sale, and price range. Approximately 600 real estate salesmen use such a listing service maintained by one bank.[58] A bank can also do such real estate management accounting jobs as calculating and collecting rents, and making disbursements for janitorial services, painting, or the like.[59]

Account reconciliation is currently one of the bank's most widespread services, with 24 percent of the automated banks in the ABA survey offering it.[60] For a fee, it tells the firm almost at once what checks are outstanding and their worth.[61]

Other new services are somewhat less related to traditional banking functions, for example, statistical inventory forecasting, which is offered by 3 percent of the automated bankers in the ABA survey.[62] One company which used such a service achieved a 20-percent inventory reduction after 1 year, which meant a saving of $400,000.[63]

These are but some of the computer-based services presently being offered; others have appeared by the score. Banks figure golf handicaps, compute interest on savings accounts daily instead of quarterly or semiannually, analyze portfolios, and offer financial advisory service on insurance, taxes, estate planning, and cash flow. This very incomplete listing in itself would indicate that the nature of the product or service offered by the banking industry has undergone considerable transformation since the advent of EDP. But this is nothing compared to some of the visions for the industry's future.

David Sarnoff of RCA foresees that each individual will possess:

> **. . . an individual credit card for use anywhere to charge his bank account electronically over a worldwide data communications network that would link up with the telephone systems of all nations. Such an arrangement could employ single input units located in all retail establishments—service stations, restaurants, hotels, and other public facilities. These would be in direct and instantaneous communication with a system of banking computers to permit the transfer of funds without the many duplicate bookkeeping and mailing steps that characterize the present credit card system.[64]**

Finally, banks with computer systems can also offer computer-based services to their correspondent banks, which leads to the impact of automation on the industry's structure and some general observations about the effects of automation on price, output, and efficiency in banking.

IV. The Impact of EDP on Price, Output, and Efficiency in the Industry

Of concern is the actual or potential impact of EDP on the industry's structure, since this may well affect price and output decisions.[65] Such an impact depends largely on whether all banks can obtain access to EDP on equal terms; or, if all cannot, on the significance of the cost advantage to those who can.

Table 1, showing the extent of automation, makes it clear that small banks do utilize computers.[66] If a small bank cannot justify buying or leasing its own computer, several alternatives are available for obtaining computer services, such as using the services of a correspondent bank or a service bureau, or entering into a joint venture with other banks or nonbanks. The ABA survey showed all these methods to be reasonably popular (see table 8).

TABLE 8. TYPE OF SERVICING ARRANGEMENT FOR BANKS USING OFFPREMISE COMPUTER SERVICING

Arrangement	Percent of banks (size in millions in deposits)					
	All	*Under $10*	*$10–$50*	*$50–$100*	*$100–$500*	*Over $500*
Total:						
Number	226	88	108	19	9	2
Percent	100	100	100	100	100	100
Correspondent banks	40	51	3	21	22	100
Service bureau	28	23	31	42	11	-------
Joint venture with other banks	12	8	10	27	45	-------
Computer servicing arrangement (nonbank)	3	1	5	5	-------	-------
Other	17	17	18	5	22	-------

SOURCE: *Banking*, November 1964, p. 107.

As might be expected, correspondent arrangements are most popular among smaller banks, while service bureaus and joint ventures are more popular among the larger banks that do not own their own computer system. However, 22 percent of the latter eventually plan to install their own computer system.

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[57] Allen, *et al., op. cit.*

[58] *1963 Proceedings, op. cit.*, p. 151. The bank is the Waterbury National Bank, Waterbury, Conn.

[59] Allen, *et al., op. cit.*

[60] *Banking,* October 1964, p. 54.

[61] *Business Week,* October 17, 1964, p. 158.

[62] *Banking,* October 1964, p. 54.

[63] *1963 Proceedings, op. cit.,* p. 151. The bank is the Waterbury National Bank, Waterbury, Conn.

[64] General David Sarnoff, "The Promise and Challenge of the Computer," Address to the Fall Joint Computer Conference, San Francisco, October 27, 1964, in Robert V. Head, "Banking Automation: A Critical Appraisal," *Datamation,* July 1965, p. 27. See also Dale L. Reistad's remarks on the "Technological Revolution in Banking," Address to the American Institute of Banking, New Orleans, June 1, 1965, mimeo.

[65] See Franklin R. Edwards, "Concentration and Competition in Commercial Banking: A Statistical Study," research report to the Federal Reserve Bank of Boston, 1964. For a critique of Edwards' findings, see Theodore Flechsig, "Banking Market Structure and Performance in Metropolitan Areas: A Statistical Study of Factors Affecting Rates on Bank Loans," Washington: Board of Governors of the Federal Research System, 1965, chapter IV.

[66] And those banks which have not automated simply may not be faced with competition from an automated bank.

While small banks use EDP equipment, the question remains whether they use it on the same terms as large banks. In theory, a joint venture among small banks ought to enable them to equalize any size advantage of large banks, as well as force others providing data processing services, such as correspondent banks or service bureaus, to be competitive. In practice, not all small banks are in a position to form joint ventures; but there may be enough who can keep the other methods competitive. In addition, the market for correspondent services in general is competitive, and correspondent services are universally available.[67]

No concrete data were found to confirm or disprove the hypothesis that small banks can obtain EDP services on the same terms as large, but those in the industry feel that unit costs of EDP processing are nearly the same for all size banks. Dale L. Reistad has written:

> With few exceptions, the $5 million bank can avail itself of automation on favorable terms through one or more means. . . . By 1965 the banking industry should be able to make a selection from a line of bank computers with special purpose systems adequate for small banks—some starting as low as $2,000 per month and some even less costly on an hours-used basis.[68]

On another occasion, Reistad said:

> Since 1955 great progress has been made in computer development, and we have come to regard announcements of new computers smaller in size with faster speeds and lower price tags as routine. . . . The bank that couldn't afford a sorter-reader in 1960 can afford an entire computer system today. The progress has been that dramatic.[69]

In 1963, a bank official said:

> A few years ago, the benefits of EDP were thought to be applicable to big banks only. But in the last 2 years, the practicality of small bank automation has been proved by small banks which have pioneered with joint ventures, service bureaus, and correspondent bank servicing arrangements. In addition, manufacturers, aware of the need, have been devoting a lot of attention to the development of equipment feasible for the broad market of small banks. Recent announcements have been made of small-scale computer systems suitable for banks in the $25 million to $40 million class.[70]

Because small banks can obtain EDP services on the same or nearly the same terms as large banks, EDP should not exert any independent influence toward changing the industry's structure.[71]

In the realm of price and output effects, EDP also has a potentially large impact on bank service charges, since fees are apparently set at cost.[72] Whether or not EDP has been responsible is conjectural, but real service charges per $100 of demand deposits have remained constant from 1961–64 after a period of steady rise (see table 5). One bank officer, who felt that EDP was responsible for preventing a service charge increase in his bank said:

> Our service charge is 10 cents a check . . . . We're able to continue the 10-cent charge now that we're automated . . . without automation in this bank, it seemed certain that we'd have to increase the service charge.[73]

V. The Impact of EDP on Manpower in Banking

EDP should increase the efficiency of the industry in several ways. Very rapid data transmission facilities should eventually reduce float, that is, money in transit which is credited to the payee before it is charged to the payer.[74] Thus, more accurate control of the money stock by the Federal Reserve Board would be possible. Since EDP gives bank management exact information on the nature of funds available for investment, reserves should be utilized more efficiently. In addition, trends in withdrawals and deposits quickly become apparent, enabling management to predict liquidity needs better.[75]

To summarize, although no hard data were obtained, small banks seem to be able to obtain access to EDP equipment on terms which do not substantially alter their position relative to large banks; thus EDP should not significantly change industry structure. EDP should also keep service charges down, especially since they are priced proportionately to cost. In addition, the banking system as a whole should become more efficient—float will be reduced, and bank management will have better knowledge of actual liquidity and potential liquidity needs.

Employment in banks, both in absolute numbers and as a percentage of the labor force, has grown steadily throughout the postwar period, despite the pervasive and far-reaching changes which took place. In 1947, employment in insured commercial banks was 411,000 or 0.68 percent of the civilian labor force.[76] In 1964, employment had increased to 761,400 or 1.03 percent of the civilian labor force.[77] The reason for this increase, of course, lies in the tremendous expansion in the amount of banking services supplied.

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[67] *Carson and Cootner, op. cit.,* p. 93.

[68] Dale L. Reistad, introduction to *Automation and the Small Bank, op. cit.,* p. 10. As mentioned above, the "few exceptions" noted by Mr. Reistad most likely do not face competition from automated banks; otherwise they would try to work out some arrangement with those banks, or other small banks faced with the same problem.

[69] Dale L. Reistad, "Technological Revolution in Banking," *op. cit.*

[70] William R. Synnott, vice president and treasurer, The New Britain Trust Co., New Britain, Conn., in *1963 Proceedings, op. cit.,* p. 64.

[71] It has been pointed out elsewhere in this paper that data processing using conventional methods shows roughly constant returns to scale, at least up to very large volumes. If, then, the unit cost of EDP is roughly the same for large and small banks; that is, if it shows constant returns to scale, the impact on structure will be negligible since relative costs will be unaffected.

[72] "In the vast majority of banks, the aim in setting service charges is to recover the actual cost of handling deposits, [even though] this price-making objective is irrational . . . ." Carson and Cootner, *op. cit.,* p. 95. "Generally, large city banks do not seek to make much in the way of profits on their service charges." Walter Lichtenstein, "Banking Service Charges," *Quarterly Journal of Economics,* May 1957, p. 321.

[73] *Nation's Manpower Revolution,* Hearings before the Subcommittee on Employment and Manpower of the Committee on Labor and Public Welfare, U.S. Senate, July 6, 1964, pp. 3450–51. The bank is the Bank of Madison, Madison, Wis.

[74] *1963 Proceedings, op. cit.,* p. 216.

[75] *1964 Proceedings, op. cit.,* p. 72.

Furthermore, as banking activity continues to increase, bank employment should keep step. Projections of banking employment were made in 1962 based on expected population growth and continuation of existing trends in checking account use.[78] These showed bank employment rising at an annual average of 4.9 percent between 1960 and 1965, and 4.7 percent from 1965 to 1975, to a total of 1,225,000 in 1975. These projections, however, underestimated actual employment in 1964 (actual 761,400 versus projected 738,800). The estimation procedure, in addition, made an allowance for the impact of electronic data processing (EDP) installation. This resulted in a still greater underestimation of actual employment in 1964 (actual 761,400 versus projected 680,900).[79]

This cannot be explained very well by positing a lag in the adjustment of personnel to the new optimum number, since case studies show that the major adjustments in personnel take place within a relatively short time after the introduction of EDP; also, high turnover in clerical positions makes it quite plausible that such adjustments can take place rapidly. Nor can higher-than-expected employment be explained by an underestimation of the spread of automation. It has already been pointed out that the great majority of banks with more than $50 million in deposits have introduced EDP, and these account for approximately five-eighths of total insured commercial bank employment.[80] In addition, some smaller banks have automated. Thus, well over half the industry's employees already work in automated banks.

A more convincing explanation is that the recent expansion of banking services, both new services fathered by automation and expansion of existing services, was underestimated. Thus, an autonomous increase in demand for banking services raised employment.[81]

It may be interesting to speculate whether or not this increase will continue, but as long as the cause of the increase is unknown, it must remain speculation. If it is assumed that there will be no large autonomous drop in demand for banking services, the projections can be regarded as a minimum. Similarly, if the stronger assumption is made that demand will stay at the higher level, projections will continue to underestimate by the same relative amount. But it should be remembered that employment was underestimated, not overestimated.

Not all the jobs created in the banking sector represent a net gain in jobs for the economy as a whole. New bank employees may be performing tasks formerly done by in-house personnel. For example, the doctor's billing was formerly done by a nurse or secretary, and a firm's employees prepared its payroll. When the bank takes over a function, the doctor or the firm may reduce its staff. However, this is not necessarily the case when services are contracted out, and to the extent that employees are kept on and given additional duties, new jobs are created.[82]

Aggregate employment statistics tell little about the actual impact of EDP on jobs and job requirements. The most concrete data concerning impact on jobs come, naturally, from case studies, and they show that the most vulnerable occupations are, as might be expected, those involving routine clerical work, especially bookkeeping and proof-machine operation.[83] At one large branch bank which installed EDP equipment, the number of bookkeepers fell from 600 to 150 within a year and a half, even though the number of branches increased by 25 percent during the same period.[84] At a small branch bank which employed 43 bookkeepers prior to the introduction of EDP, the jobs of bookkeeper and proof-machine operator were completely eliminated.[85] At a large unit bank, the clerical staff before conversion to computer bookkeeping numbered 2,918, including 211 in commercial bookkeeping and 51 in trust tabulating. Two years later the total clerical staff numbered 2,958, but only 100 were in the commercial bookkeeping department and 31 in trust tabulating.[86] It is estimated that one-half the workers currently in the banking industry may be in moderately or highly vulnerable occupations.[87]

While bookkeepers and proof-machine operators have been disappearing, new occupations have been created. The list of new job titles would sound quite foreign to the ears of a banker of a generation ago: Encoders, reader-sorter operators, data control clerks, computer operators, keypunch operators, computer room supervisors, programers, and systems analysts. The work done by the 450 bookkeepers eliminated at the large branch bank is now done by 122 people in the data processing center. Eventually about 15 people in the center will do the work of 40 savings bookkeepers.[88] The net effect of installing EDP at that bank will be to reduce the total staff needed to handle the preconversion volume of business by 6 to 7 percent. At the small branch bank there was a drop from 75 to 55 in the number of people employed in data processing jobs in 2½ years. It is estimated that 100 people would have been required to process the increased volume of business with the older methods.[89]

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[76] U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings for the United States, 1909–62.*

[77] *Monthly Labor Review,* July 1965.

[78] Wiener,, *op. cit.*

[79] *Ibid.*, pp. 992–994. It was estimated that EDP would reduce the projected total employment by about one-sixth. This figure was derived by assuming that bookkeepers' employment (20 percent of total bank employment) would be reduced 50 percent and that other vulnerable occupations (comprising 30 percent of the total) would have their employment reduced 20 percent, ceteris paribus.

[80] Federal Deposit Insurance Corporation, *1963 Annual Report,* p. 76. 54.5 percent of the industry's work force are in banks with more than $100 million in deposits.

[81] Autonomous, that is, to a model which includes population and a time trend as variables to explain demand; the model could also include a price variable without helping to explain the increase. Which price or prices influence employment the most is problematical, but none showed a continual fall in the period.

[82] ". . . termination of employees [who perform billing in doctors' offices] seems to be rare . . . ." Allen, *et al., op. cit.*

[83] Proof of deposit is "basically an operation in which the items deposited are relisted and their amounts totaled to determine the accuracy of the total listed on the deposit slips. Proof machines are sorting machines which keep track of the total numbers and dollar amounts of the items sorted . . . . They are used to sort checks and other items." Stanford Research Institute, *op. cit.,* p. A 22. Proof-transit operations combine proof operations with the preparation of items for the bank's own bookkeeping department or for sending to other banks or clearinghouses.

[84] *Ibid.,* p. A 14.

[85] *Ibid.,* A 19.

[86] *1964 Proceedings, op. cit.,* p. 48. The bank is the First National Bank of Chicago.

[87] Wiener, *op. cit.,* pp. 992–994. For the method of estimation, see footnote 79.

It is a commonly held notion that "computerization" has upgraded the skill mix in banking. For example, a former president of the American Bankers Association has said that automation means that "better jobs are created requiring higher degrees of skill and knowledge, and a great many boring repetitive clerical positions are eliminated." [90] There is some merit in this claim. The number of tedious data processing jobs has been cut, and they make up a smaller proportion of the total banking work force. New jobs, such as systems analyst and programer that require a much higher skill level than the old data processing jobs, have been brought into existence. Jobs pertaining to some of the new, customer-oriented services, many of them still in the planning stage, may be more interesting than the older jobs. Nevertheless, it would be misleading to assume that a massive upgrading will take place, for a large proportion of jobs created up to this point are relatively low rated. Encoders are a case in point: Encoding "is a low-grade job which is easily and quickly learned, requiring only the ability to operate a 10-key keyboard." [91] At one bank, "Due to the simplicity of operator training for single pocket proof encoders, the job, as related to our job evaluation scale, has been downgraded three grades and reduced from an average base of $68 to $53 per week." [92] An EDP clerk is only "a slightly higher grade position than that of encoder. . . ." [93] At the large branch bank referred to above, approximately 70 percent of the jobs created were low rated, while at the small branch bank they comprised around 50 percent of the new jobs.[94]

Duties of supervisory personnel have clearly been affected by automation. The operations officer who formerly supervised clerical work on a full-time basis often finds these duties take only part of his time, leaving him free to devote time to, say, public relations. Similarly, the branch manager who previously spent much of his time completing reports for central management and generally "keeping shop" now has time free to concentrate on less routine matters. "One major benefit to be derived from automation . . . is the removal of the shackles of running a paper processing workshop so as to permit you to become bankers again." [95]

The establishment of a central data processing center plainly shifts the place of work for data processing jobs. For example, part of the work now handled in the center was formerly done by branch bank tellers before or after "banking hours." If, as a result, tellers must now work only during banking hours, their jobs could conceivably become part time which would open them to new sources of supply (e.g., married women).[96] A trend toward more part-time tellers already exists. A large automated California branch bank has 30 percent more part-time tellers now than 5 years ago, and would like to make two-thirds of its teller force part time.[97] EDP has also virtually eliminated overtime in data processing jobs, which used to occur frequently for demand deposit accounting.[98]

The personnel turnover, together with the new jobs made necessary by the industry's growth, immensely facilitates the adjustment of manpower to the new optimum and enables that adjustment to be made relatively quickly. There are abundant case histories of automating banks which, because of high turnover and growth, were able to establish the policy that no employee would lose his job as a result of automation.[99]

> **Staff reduction is *not* a problem. Most banks have sufficient attrition to take care of personnel reductions within a very short time, even the very small banks. The conversion of demand deposit accounting to computer processing resulted in personnel reduction of 7 to 10 percent of the total staff in each of our banks. Most banks will experience this much turnover within a few months.[1]**

Bank officials think the new equipment will cut the turnover rate by eliminating many of those jobs where turnover was highest.[2] As one banker put it, "As we look at many of the functions the computer is performing, we find that these were jobs which were becoming increasingly more difficult to fill and which had the highest rate of turnover because of their routine, tedious nature." [3] In one case, the turnover rate in the transit area was cut 50 percent after automatic equipment was installed.[4] A caveat should be entered here, however. Many of the old jobs were held by young women who have relatively high involuntary turnover rates.[5] The turnover rate after EDP installation will be lowered only insofar as the voluntary turnover rate is lowered (because of less tedious work) and less hiring is done in age-sex groups with high involuntary turnover rates. But if new jobs are staffed with young, female high school graduates, it is quite possible that turnover rates will remain high.

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[88] Stanford Research Institute, *op. cit.*, pp. 13–15.

[89] *Ibid.*, p. B 12.

[90] William F. Kelly, *1963 Proceedings*, *op. cit.*, p. 34.

[91] Stanford Research Institute, *op. cit.*, p. A 17.

[92] *1963 Proceedings*, *op. cit.*, p. 131. The bank was the First New Haven National Bank of New Haven, Conn.

[93] Stanford Research Institute, *op. cit.*, p. A–17.

[94] Calculated from data in *ibid.*, pp. A–16, A–17, and B–14.

[95] Dale L. Reistad, address before the 67th Annual Convention of the Nebraska Bankers Association, Lincoln, Nebr., May 7, 1964, mimeo.

[96] See Stanford Research Institute, *op. cit.*, pp. A–7, A–10.

[97] *Wall Street Journal*, Aug. 3, 1965.

[98] Stanford Research Institute, *op. cit.*, pp. 15, 19; *1963 Proceedings*, *op. cit.*, pp. 127, 131.

[99] See, for example, Stanford Research Institute, *op. cit.*, pp. A–19, A–20, B–12; *1963 Proceedings*, *op. cit.*, p. 33; *Nation's Manpower Revolution*, *op. cit.*, p. 3448.

[1] William R. Synnott, vice president and treasurer, New Britain Trust Company, New Britain, Conn., *1964 Proceedings*, p. 181. Emphasis in original.

[2] *Ibid.*, p. 284. It should be added that there is some indication of a tight labor market for those jobs at this time.

In sum, bank employment has increased relative to the labor force, and should continue to increase. The increase has exceeded expectations, probably because demand for banking services is rising faster than its long-term trend. Bank employment should continue to increase, since the growth of demand for banking services should create jobs faster than EDP installation can eliminate them. This conclusion is buttressed by the fact that well over half the industry's employees are working in banks already automated; therefore, many of the jobs vulnerable to EDP have already been eliminated.

Experience has shown that EDP does not lead to a vast upgrading of skill requirements. New skills are necessary, in some instances highly complex skills, but the majority of the new jobs do not use skills more demanding than present ones. The work force may be composed of more part-time workers, and the high turnover, which eased adjustment to the new equipment, may or may not fall significantly, depending on the characteristics of the new work force.

VI. Legal Obstacles to Technological Change in Banking

The benefits of recent technological advances in banking have not been fully realized because of legal obstacles. There is little or no need, for example, for highly elaborate debt and equity certificates which computers find hard to process.[6] Checks, regardless of amount, are presently standardized for EDP machines, and only State laws and regulations of organized stock exchanges prevent standardizing debt and equity certificates.

Certified checks are another instance of a model-T on an expressway. Bothersome and superfluous, they do not easily fit into automated systems, since the MICR account number on the check must be obliterated in order for the check not to be charged against the writer's account in the normal sorting process. And certified checks are not a necessary evil, since a cashier's check provides equally good assurance that the check will be honored. Unfortunately, several Government statutes and regulations still require payment by certified check.[7]

Up until 1962, in 21 States small national banks were at a competitive disadvantage to small State banks. At that time laws of those States permitted State banks to invest in a bank services corporation; that is, to set up an EDP center jointly with other banks, none of which had enough volume individually to justify a computer.[8] The Bank Service Corporation Act of 1962 extended this privilege to national banks, but with the provision that: "No bank service corporation may engage in any activity other than the performance of bank services for banks." [9] This section of the law has been interpreted differently in different places. Some have taken it to mean that banks may not use these centers to perform anything other than the more or less traditional banking function; e.g., statistical inventory control cannot be performed. Others interpret any service a bank offers as being ipso facto a bank service. Since the State laws do not contain this clause, the national banks which choose the narrow interpretation are handicapped.

A bill was introduced in the House of Representatives in 1963 and again in 1965 which would clarify this ambiguity by prohibiting all banks (not just those in bank service corporations) from performing

> any clerical, administrative, bookkeeping, accounting, or other similar service for their depositors, borrowers, or other customers except to the extent that such services are a necessary incident to the proper discharge of lawful functions of such bank as a depository, lender, trustee, or agent.[10]

Public accountants and computer service bureaus, whose services are competitive with some of the bank's customer services, actively supported this bill. As written, the bill raises numerous problems of interpretation, but its intended effect is clearly to prevent banks from offering many of the new services described above. As such, it must be regarded as a potential obstacle to full realization of the technological change in banking.

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[3] Alfred E. Langenbach, vice president of the First National Bank of Chicago, *1964 Proceedings, op. cit.*, p. 49.

[4] *1963 Proceedings, op. cit.*, p. 127. The bank is the Iowa-Des Moines National Bank, Des Moines, Iowa.

[5] Involuntary turnover refers to a woman's leaving because of marriage, pregnancy, or a husband's transfer, among other things.

[6] See Dr. Anthony C. Oettinger, chairman, Committee on the Harvard Computer Center, Cambridge, Mass., *1964 Proceedings, op. cit.*, p. 40; and John A. Mattmiller, vice president, Northern Trust Co., Chicago, Ill., *1963 Proceedings, op. cit.*, p. 93.

[7] For example, 19 U.S.C. § 198. Credit for this reference is due to Roy N. Freed, Esq., *1964 Proceedings, op. cit.*, p. 400.

[8] *National Bank Legislation,* Hearings Before Subcommittee 1 of the Committee on Banking and Currency, House of Representatives, July 19, 1962, pp. 38, 55.

[9] *U.S.C., Sect. 1861–65.*

[10] H.R. 9548, 88th Congress, 1st sess.; reintroduced as H.R. 112, 89th Congress, 1st sess.

Conclusion

Banking is a fruitful subject in a study of the adjustment of an industry to technological change, because such change has been rapid and widespread in the industry. The change has basically been in the techniques used to process financial data; specifically, new machines process such data with more speed and less manpower. The fundamental reason that banks have adopted the new technology was not because conventional machines were impractical for meeting the increased demand, but because the new machines were a cost-saving innovation. In addition, banks could offer a much wider range of customer services, and specialized services are the main vehicle of competition in the industry. The wider range of services has already substantially altered the industry's product, and even more radical changes are now being discussed and planned. Since all size banks appear to have access to the new equipment on nearly equal terms, the innovations should have little effect on the structure of the industry. By improving the speed and accuracy with which banks can obtain information, the banking system should become more efficient—float will be reduced and potential liquidity needs and funds available for investment will be predicted with greater accuracy and certainty. Service charges will be kept lower. Thus, there are real social benefits from the new technology. At the same time, because of the growth in demand for banking services and high turnover, most of the necessary personnel adjustments can be made through attrition hiring, which keeps the social costs of displacement low. Care should be taken not to overemphasize the nature of the skills required to man the new machines. New jobs have indeed been created which need highly skilled personnel, but the majority do not fall into this category. There has also been modification of some old jobs so that they are not as routine, and, in some instances, they do not require full-time personnel. Certain anachronisms of a legal nature still prevent banks from fully utilizing the new technology. One is the nonstandardized debt and equity certificate; another is the use of the certified check.

This study has presented concrete details of adjustment to technological change of a single white-collar industry. Nevertheless, analogies to banking can be found in closely related sectors of the economy. In this period, for example, insurance has shown many of the same characteristics, with the number of insurance policies increasing rapidly and employment rising steadily, despite the widespread introduction of EDP.[11] In general, experiences with the introduction of EDP into offices show similarities to banking. The number of employees needed to process a given output falls, although a small number of better paid positions are created. There is no strong upgrading nor downgrading of the work force. Workspace is saved, and management receives more information on operating conditions. Personnel adjustments are usually made without extensive layoffs.[12]

Studies of other white-collar service industries might reveal additional similarities. But that must await future research.

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[11] See U.S. Department of Labor, Bureau of Labor Statistics, *Technological Trends in 36 Major American Industries*, updated, pp. 100–101; and *ibid.*, *The Introduction of an Electronic Computer in a Large Insurance Company*, October 1955.

[12] See U.S. Department of Labor, Bureau of Labor Statistics, *Adjustment to the Introduction of Office Automation*, May 1960; Richard W. Ricke and James R. Alliston, "Impact of Office Automation in the Internal Revenue Service," *Monthly Labor Review*, April 1963, pp. 388–393; and Floyd C. Mann, "Psychological and Organizational Impacts," in *Automation and Technological Change*, ed. John T. Dunlop; Englewood Cliffs, N.J.: Prentice-Hall, 1962.

APPENDIX

Relationship of Risk to Investment

We can make the ideas expressed in section I regarding the relationship of risk to investment more formal. Risk is normally thought of as the variance in a distribution of expected profits or losses—the higher the risk, the larger the variance. Let a and b be the limits on losses and gain, let x be a random variable taking the values of the various outcomes ($a \leq x \leq b$). X can be appropriately discounted. Let $f(x)$ be the probability distribution of outcomes, $g(x)$ the utility or disutility of various outcomes, and c the cost of the investment. Assume c fixed for now, and assume $f(x)$ is not correlated with bank size. Then the bank invests if its expected utility, $a \sim b\ f(x)g(x)dx > 0$, where $g(x) \leq 0$ for $x \leq c$ and $g(x) > 0$ for $x > c$. We have made an assumption about $g(x)$ for small banks and large banks which means that for a given $f(x)$ and a given c, the integral is more likely to be positive for large banks than small banks. Specifically, the assumption is that for small banks $g(x)$ has a larger negative value (for $x < c$) relative to the positive value (for $x > c$) for each pair of $c \pm x$ than is the case for large banks (i.e., $\left|\frac{g(x)\ \ (x<c)}{g(x)\ \ (x>c)}\right|$ for small banks $>$ $\left|\frac{g(x)\ \ (x<c)}{g(x)\ \ (x>c)}\right|$ for large banks for each pair of $c \pm x$.) Hence, the conclusion that large banks will invest first.

If c varies directly with the size of the bank, this conclusion is not as tidy. Fortunately, the assumption of c constant seems to be a reasonably valid one for the late 1950's and early 1960's, which was when risk was large enough to be a significant factor in determining what size bank automated. If c is smaller for small banks, the maximum loss is lower, and this may reduce the element which tends to make the integral negative. (It does not reduce the negative element if, at the same time, the probability of small losses is increased significantly.) But the smaller investment may also reduce the probability of the large values of gain. (This would be the case if the small bank could apply its large EDP system to many profitable areas, but cannot apply its small EDP system to all those areas, but it is not so if the large computer could not be completely utilized by the small bank, since the possibility of relatively large gains in that case would not be present from the start). In other words, the variance is likely to be less on a small system. Whether the reduction in variance is enough to offset the greater aversion of small banks to any given variance is an empirical question.

TECHNOLOGICAL CHANGE IN PRIMARY STEELMAKING IN THE UNITED STATES, 1947–65

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Technological Change in Primary Steelmaking in the United States, 1947–64

I. The Nature and Impact of Changes in Steelmaking

Steelmaking starts with metallic iron in the form of hot or cold pig iron from blast furnaces or iron and steel scrap. The steel furnace, which produces molten steel, uses one or more of these materials, sometimes with small quantities of others. Three types of steel furnace are in common use today: Open hearth, oxygen converter, and electric furnace. The open hearth uses molten pig iron (hot metal), cold pig iron, and scrap in varying proportions; the oxygen converter uses about 75 percent hot metal and 25 percent scrap; and the electric furnace ordinarily uses an all-scrap charge.

Some types of steel are processed by vacuum degassing as they come from the furnace. The steel is then cast into a solid shape by one of several methods. In conventional casting, the steel is poured into an ingot mold. When it is solidified, the mold is stripped off and the ingot is placed in a soaking pit, heated, and taken to a blooming mill to be rolled into a semifinished shape. In continuous and pressure casting, the steel is cast directly into a semifinished shape. A small proportion of all steel goes directly to the foundry to produce cast steel products. Most steel, however, is made into semifinished shapes ready for the hot rolling mill.[1]

Steelmaking is only a part of the operations of integrated steel companies, which perform a complicated sequence of productive functions. Although most of the product passes from stage to stage within single firms and does not enter the market, a comparison of approximate prices of intermediate products gives some indication of the relative importance of the different stages. (See table 1.)

Other steel company products are more highly finished or processed further, and are correspondingly higher priced. Alloy and stainless steels, a minor fraction of total output, require more expensive ingredients and in some cases more costly processing, and sell for higher prices. As a rough approximation, steelmaking strictly defined accounts for about one-third or one-quarter of the market value of products sold by a typical integrated steel company. This study deals with technological change in this limited segment of the steel industry.

TABLE 1. APPROXIMATE PRICES OF INTERMEDIATE STEEL PRODUCTS

Product category	*Approximate published price per ton*[1]
I. Metallic inputs to steel furnaces:	
Merchant pig iron (cold)	$60.00–$64.00
Hot metal (estimated intrafirm value, no published price quotations)	$35.00–$39.00
Steel scrap, grades commonly used in steelmaking	$30.00
II. Steel from furnace, with little or no processing:	
Ingots	$80.00–$82.50
Semifinished shapes	$84.00–$130.00
III. Steel products commonly sold:	
Hot-rolled products	$111.00–$130.00
Cold-rolled and cold-finished products	$130.00–$153.50

[1] Market prices are published weekly in the trade publications *The Iron Age* and *Steel*. The prices here are from *Steel*, Nov. 1, 1965.

In the 1930's and 1940's open-hearth furnaces produced 90 percent of the United States' supply of steel. This share dropped to less than 75 percent in 1965 and will be not far from 60 percent when new steel furnaces now ordered or under construction are completed. If the present relation between capital and operating costs of competing furnace types does not change radically, no new open hearth furnaces will be built, and existing ones, even the most modern and efficient, will be gradually retired and replaced.[2]

Oxygen converters have been in operation in this country since 1954, and their cost advantage over the open hearth has been conclusively demonstrated. From about 1961 the use of the new type of furnace has spread rapidly, and most large scale steel plants with their own blast furnaces will install oxygen converters for expansion and to replace worn-out or obsolete open hearths.

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[1] A technical description of steelmaking processes may be found in *The Making, Shaping, and Treating of Steel*, 8th ed., Pittsburgh, United States Steel Corp., 1964.

[2] *Final Report on Technical and Economic Analysis of the Impact of Recent Developments in Steelmaking Practices on the Supplying Industries*, Columbus, Ohio: Battelle Memorial Institute, Oct. 30, 1964. (Referred to below as *Recent Developments in Steelmaking Practices*.)

Because oxygen converters require hot metal as a major part of their metal supply, the supply of ore and the capacity of blast furnaces to produce hot metal sets a theoretical limit to their increasing use. However, blast furnace output in recent years has been great enough for oxygen converters to supply about three-quarters of total steel output at current scrap ratios. The availability of low priced steel scrap may set an economic limit to the use of oxygen converters because current types will accept only limited amounts of scrap.

Electric furnaces, however, work efficiently on a 100-percent scrap charge, and because scrap is at present substantially cheaper than hot metal, electric furnaces are the lowest cost type of new steelmaking equipment in many places. Electric furnaces have also been used for making alloy, stainless, and specialty steels, since the quality of the product can be controlled with precision. Because the cost disadvantage of small scale operation is less for electric furnace shops than for other types, the electric furnace offers further economic advantages in local or specialized markets.

The proportions of oxygen converter and electric furnace capacity to be installed in the near future will be strongly influenced by the market supply and price of scrap. Some of the large companies now adopting oxygen converters are also adding electric furnace capacity, and a number of small open hearth shops are being converted to the electric process. A few steel fabricators have found it profitable to install electric furnaces and produce their own semifinished steel instead of buying it from larger steelmakers. Thus, continued increase in the number of scrap charged electric furnaces would pose several important questions: At what point will increased demand begin to push up prices? How much more scrap can be made available before price rises wipe out the cost advantages of electric furnaces? To what extent can oxygen-converter operators learn to increase scrap ratios? How many old open hearths will continue to operate, their other disadvantages offset by their ability to use large proportions of cheap scrap in their charges? How much can the cost of hot metal be lowered by further improvements in ore processing and blast furnace operation? The answers to these questions will in good part determine the share of the electric furnace in U.S. steel production. The share may well be substantially higher than the present 10 percent (see table 2); it is not likely to grow to 50 percent.

An important, but at this stage imponderable, influence on these shares will also be felt as two new processes, continuous casting and pressure casting, are adopted in more steel shops. These innovations, particularly continuous casting, are well-suited to both oxygen converters and electric furnaces, and are included in the design of many of the new steelmaking facilities currently being planned. They will probably hasten the pace of change, because the construction of completely new, integrated plants embodying all available improvements and innovations apparently has advantages over a piecemeal introduction of changes in existing plants. Therefore, within a few years, a fairly substantial share of the Nation's steel capacity will be in the form of large units with new furnaces and continuous casting facilities.

TABLE 2. U.S. STEEL PRODUCTION, WITH PROPORTIONS PRODUCED BY VARIOUS TYPES OF FURNACES [1]

Year and month	Production (1,000 tons)	Percent produced in—		
		Open hearth	Oxygen converter	Electric furnace
1965: May	12,012	73.3	16.3	10.1
April	11,966	73.2	15.8	10.4
March	12,317	73.5	15.4	10.4
February	10,866	73.6	15.5	10.2
January	11,830	74.2	15.3	9.8
1964: December	11,612	74.2	15.4	9.7
November	11,292	75.1	14.4	9.9
October	11,568	76.5	13.0	9.9
September	10,669	76.3	12.4	10.6
August	10,515	76.5	12.6	10.1
July	10,106	77.3	12.3	9.7
June	10,185	77.6	11.9	9.8
May	11,060	77.9	11.8	9.6
April	10,560	78.2	11.1	10.0
March	10,497	78.9	10.5	9.9
February	9,485	79.5	9.6	10.1
January	9,526	79.1	9.7	10.4
1963	109,261	81.3	7.8	10.0
1962	98,328	84.4	5.6	9.2
1961	98,015	86.2	4.0	8.8
1960	99,282	87.0	3.4	8.4
1959	93,446	87.4	2.0	9.1
1958	85,255	89.0	1.6	7.8
1957	112,715	90.2	.5	7.1
1956	115,216	89.3	.4	7.5
1955	117,036	90.0	.3	6.9
1954	88,312	91.0	----------	6.2
1953	111,610	90.0	----------	6.5
1952	93,168	88.9	----------	7.3
1951	105,200	88.6	----------	6.8
1950	96,836	89.1	----------	6.2
1949	77,978	90.1	----------	4.9
1948	88,640	89.5	----------	5.7
1947	84,894	90.6	----------	4.5

[1] Small amounts of Bessemer steel are not included in this table.

SOURCES: Monthly figures from *Steel*, fourth issue of each month.
Annual figures from *Annual Statistical Report*, American Iron and Steel Institute, 1963.

These new casting processes substantially reduce the minimum investment in equipment required to convert steel from the molten product of the steel furnace into semifinished forms ready for the rolling mill. It is therefore possible for small steel producers to enter the industry with a comparatively small investment by installing small electric furnaces in combination with continuous casting machines; and a number of firms have done so. While their share of total output is now little more than negligible, their existence significantly affects the competitive characteristics of the steel industry. In effect, the entry barrier of high capital requirements for primary steel production has dropped by a perceptible margin.

During the third quarter of the 20th century, a very large proportion of the expensive and durable steelmaking equipment—open hearth furnace, teeming floor, ingot molds, soaking pits and blooming mills—that made up the standard large scale steel shop of the 1950's, will have been replaced by equipment with lower capital and operating costs. Several kinds of economic change can be anticipated as a result of this transition.

Productivity and Costs

Technological change in steelmaking will almost certainly offset, to some degree, conditions which the industry has experienced and complained of in recent years: Rising labor costs, the expanding availability of competing materials, and increasing competition from foreign steel producers. For the calculable future, the steel industry will probably be a source of inexpensive and useful products—at least, there is no technological reason why it should not. However, it is not likely to be a rapidly expanding employer of labor. Steelmaking is probably entering that group of industries, of which agriculture is perhaps the senior member, where real labor cost per unit of output declines as fast as, if not faster than, total output increases.

Competitive Structure of the Industry

The new steel technology opens particularly attractive opportunities to two kinds of plant development. Large integrated plants in the 1.5 to 3-million-ton size range[3] with ore supplies, coke ovens, efficient blast furnaces, and large oxygen converters, can be operated profitably enough to warrant investment by major companies, even those with some excess open hearth capacity. Currently developing refinements in technology make it likely that the capacity of such plants may be increased at moderate cost. The market in about 1975 will have room for probably fewer than 50, and perhaps no more than 20 such plants.[4] Much of the present such investment is being made by the 8 largest firms in the industry, and virtually all by the approximately 20 companies producing a million tons a year or more. Therefore no great change in the loosely oligopolistic organization of the industry can be anticipated. If anything, some of the existing large and medium size firms may be squeezed out.

A second trend derives from the comparatively low investment requirements and operating cost disadvantages of small electric furnace, continuous casting plants as compared with larger plants, and the currently low prices of scrap relative to hot metal. These cost relationships may make it possible for a number of small firms using this plant design to enter the industry.

The large firms are unlikely to maintain effective barriers to this type of entry. While they have some advantage in engineering skills, the margin is not conclusive. They are not likely to gain any substantial degree of control over the supply of market scrap, or to use predatory methods of competition, aggressive mergers, or other advantages of size to suppress competition from smaller firms. If public policy leans toward encouraging active competition in the steel industry, antitrust enforcement and such Federal agencies as the Small Business Administration and the Area Redevelopment Agency can promote small plants and counteract any tendency among large firms to preempt such opportunities.

Resource Conservation

The choice between the two sources of metallic iron, ore and scrap, presents an important problem in the conservation of natural resources. As it stands now, the large firms have invested heavily in low cost methods of reducing types of ores in abundant supply, and are able to provide a very large proportion of metal requirements for years to come with existing equipment. The potential supply of scrap is also very great. Most steel is used in forms which theoretically could be returned to the industry as scrap if this paid. In practice, the industry uses practically all the considerable quantities of "home" scrap produced in its own plants, substantial amounts of the scrap produced by large scale, steel using industries, and only a small proportion of the scrap from small scale industry and wornout and discarded steel products. Further improvements in mining, processing, and reduction of ore would favor the use of still more ore in steelmaking, and improve the competitive position of the large oxygen converter plant. The scrap charged electric furnace would gain if the costly processes of collecting, sorting, and preparing scrap could be made more efficient, or if measures taken to combat the nuisance of accumulations of junked autos and other scrap materials brought more scrap into market channels.

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[3] Unless otherwise specified, references to size in this study are to annual rates of production of ingots and steel for castings. The unit is short tons of 2,000 lb.

[4] In 1960 there were 35 individual plants in the United States with reported capacities of 1.5 million tons a year or more. See appendix and *Directory of Iron and Steel Works in the United States and Canada*, New York: American Iron and Steel Institute, 1960.

II. Cost Comparisons Among Types of Steelmaking Processes

The lowest cost method of producing steel in the United States is by a large electric furnace using an all scrap charge. A fairly close competitor is the large oxygen converter, which uses a 75 percent hot metal and 25 percent scrap mixture. Smaller shops of both types operate at a moderate cost-per-ton disadvantage. Large open hearth shops with their own blast furnaces are substantially more costly on a full cost basis. However, although specific cost statistics for individual plants are not available, a number of owners of large, modern, open hearth furnaces regard the original investment as a sunk cost, and believe it pays to keep them in operation and make moderate investments in improvements. Smaller open hearth shops using cold metal charges seem to be at a conclusive disadvantage. Not a few of them have been or are being replaced by electric furnaces, and the survivors seem explainable only in terms of severe capital rationing, extreme reluctance on the part of management to depart from familiar production methods, or unusual local conditions.

Estimates of the cost of producing steel in open hearths, oxygen converters, and electric furnaces were made in a 1964 study by the Battelle Memorial Institute.[5] Hypothetical plants were defined for the three types of furnace, for three plant sizes (annual capacities of 1,500,000 tons, 500,000 tons and, electric furnaces only, 200,000 tons), and for a number of variations in operating practice. For each plant size and type, three categories of cost were estimated: Fixed charges, including capital costs, property taxes, insurance, depreciation, and the like; "cost above," or operating cost, exclusive of metallic materials in the furnace charge; and metallics, including pig iron, hot or cold, iron and steel scrap, plus the relatively small amounts of other materials required. Assumed prices for metallics were thought to be reasonably current: Hot metal at $39 a ton for small plants, $35 for large; scrap steel at $30 a ton for grades used in open hearth and oxygen converter plants, and $27 for those used in electric furnaces. Results of the study are summarized in table 3.

This comparison clearly shows that the oxygen converter has a substantial advantage over the open hearth furnace in capital and operating costs; the electric furnace has an advantage in both capital costs and the ability to use low priced metallics; and whether the price of scrap is high or low relative to that of pig iron, oxygen converters, electric furnaces, some combination of the two will in most circumstances produce steel at lower cost than the open hearth. With metallics amounting to half to two-thirds of total cost, the choice tends toward the oxygen converter when hot metal is cheap and scrap is dear, and toward the electric furnace when the opposite is the case.

TABLE 3. ESTIMATED COSTS OF PRODUCING STEEL, VARIOUS METHODS

Costs	Estimated cost per ton in—		
	Open hearth	Electric furnace [1]	Oxygen converter
Total cost per ton	$56.94–$64.67	[1] $48.79–$57.64	$53.14–$62.93
Metallics	$37.22–$40.85	[1] $29.26–$36.89	$38.21–$44.59
Cost above	$15.58–$20.88	$17.26–$19.62	$12.82–$17.33
Fixed charges	$4.01– $5.50	$2.23– $3.45	$2.11– $2.57

[1] The highest electric furnace estimates for metallics and total cost per ton were based on the assumption that the plant would use 50 percent scrap and 50 percent hot metal. They are substantially higher than estimates based on a 100 percent scrap charge.

SOURCE: *Technical and Economic Analysis of the Impact of Recent Developments in Steelmaking Practices on the Supplying Industries*, Columbus, Ohio: Battelle Memorial Institute, Oct. 30, 1964, appendix tables A-1 through A-24.

Total cost estimates in this comparison include hot metal costs substantially higher than scrap prices in the current market; thus the electric furnace is given a clear cost advantage over the oxygen converter for large and small steel shops. Yet, firms investing in new capacity are almost all choosing the oxygen converter for large plants. Against at least 16 oxygen process plants ordered or started up in the past 5 years, the only new electric shop to approach the million ton capacity level is Republic's addition to its alloy division in Canton, Ohio. If Battelle's operating-cost figures are not drastically wrong, the steel companies themselves must view the cost of hot metal as substantially less than the research staff's estimate of intrafirm transfer values.

The market in which scrap is procured and the "market" conditions that determine the cost of hot metal to the steel department of an integrated firm differ enormously. Hot metal is produced in blast furnaces which are expensive, long-lived, and built in large, indivisible units. Largely because individual blast furnaces have been greatly enlarged and modernized in recent years, the existing stock includes a good deal of excess capacity.[6]

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[5] *Recent Developments in Steelmaking Practices, op. cit.*

[6] "Blast Furnaces Charge Back," *Iron Age*, June 17, 1965, p. 59, reports that 150 blast furnaces are currently in operation. This means that at least 113 of those reported in existence in 1960 are temporarily or permanently idle.

Furthermore, a very large proportion of the blast furnace capacity belongs to firms that own coke ovens, ore beneficiating plants, railroads, ships, and coal- and iron-mines. This heavy and long lasting investment in iron producing facilities strongly suggests that, at current output rates and scrap ratios, major integrated companies can produce pig iron at marginal costs somewhat lower than the costs estimated in the Battelle estimates. Apparently this is true even for newly installed modern blast furnaces. Armco has recently built a new blast furnace at Ashland, Ky., billed as the largest and most modern in the world, which will supply a large proportion of the hot metal needed in its steel plant there. The behavior of the industry, in short, permits us to infer that for large firms the Battelle operating cost comparisons are approximately correct, but the estimate of the relative costs of scrap and hot metal is either wrong or not applicable when actual decisions are made.

Accurate comparisons are also inhibited because there is no open market with published price quotations for hot metal.[7] Published prices of such related commodities as coke, iron ore, and pig iron apply to markets which handle only small and unrepresentative proportions of the total output. Steel scrap, on the other hand, is bought and sold in fairly active markets where prices are set, announced, and frequently changed by competing buyers and sellers. Steelmakers show distinct signs of discomfort in this kind of market: They are happiest with scrap they produce and reuse themselves; they take fairly kindly to the practice of buying back and recycling scrap from their own large scale customers; and they regard the unpredictability of supplies, quality, and prices in the open scrap market as a reason for avoiding heavy reliance on it.[8] After all, they are accustomed to buying ore deposits planned for decades of use; they build blast furnaces that will last indefinitely; and they seek systematically to avoid short-run price fluctuations in the market for their products. Scrap prices tend to be low when steel demand and operating rates are low, and high when steelmakers are striving for high rates of production. This is not likely to seem congenial to steel company decisionmakers.

For a period during and just after World War II, the great high grade ore deposits of the Lake Superior region seemed close to exhaustion and with no immediate accessible substitutes in sight, the industry had to make real efforts to expand the scrap supply. But this trend has been reversed by discovery of new ore bodies, the introduction of new beneficiation processes,[9] and the opening of new transportation routes. As a result, scrap prices have been low and falling in recent years, even during periods of high steel production.

Yet for actual or potential steel producers without their own supplies of hot metal, and for those with limited or obsolescent facilities for producing it, the cost advantage of the scrap charged electric furnace seems almost conclusive. The cost penalty for small scale production is moderate: The Battelle study finds that a 200,000-ton electric furnace plant can produce a ton of steel at a cost of only $3.08 greater than a 1,500,000-ton plant. Therefore, a moderate widening of the gap between scrap and hot metal prices, or a limited or geographically isolated market may offer opportunities for moderate- or small-size plants.

The cost penalty of small scale production becomes even less if continuous casting is used. The Battelle study estimates that a 500,000-ton plant with continuous casting can produce 8 by 8 inch blooms for $14 a ton less than can a 1,500,000-ton plant using conventional casting methods, and for only $0.10 a ton more than a 1,500,000-ton plant also using continuous casting. The advantage for smaller billets is apparently at least as great.[10] The president of Roblin Steel Corp. claims that his electric furnace and continuous casting plant will produce about 120,000 tons of billets a year for a "safe $20 a ton less than the $115 per ton that is the market price for billets." [11]

Two kinds of scrap market conditions are likely to make possible the growth of electric steel production. Where ore and hot metal are not available, even comparatively small supplies of local scrap can make steel production economically feasible on a small scale. The possibilities are most promising where the local market will absorb reinforcing bars, small structural shapes, and other products that can be rolled from small billets. Where steel producers and metalworking industries are concentrated, the shift from open hearths to oxygen converters may leave a local scrap supply that would enable electric furnaces to share the local steel market. If entry is reasonably unobstructed, or if large steel firms make rational cost minimizing decisions about the share of output assigned to oxygen converters and electric furnaces, electric furnace production should expand to the point where increased demand for and rising prices of scrap will about balance the longrun costs of electric and oxygen converter production.

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[7] There is no physical reason why molten pig iron should not be produced in the blast furnaces of one company and sold to another. However, this is virtually never done in the United States, and if it were, the shipping arrangements would probably call for long-term, large-scale contracts which would not result in representative market price quotations.

[8] One of the drawbacks to the use of scrap purchased in small batches from varied sources is the cost of detecting and eliminating nonferrous metals which may produce undesirable "tramp" alloys.

[9] Beneficiation is defined as "the methods used to process ore to improve its chemical or physical characteristics in ways that will make it a more desirable feed for the blast furnace." *The Making, Shaping, and Treating of Steel, op. cit.*, p. 184. Processes developed and introduced in the postwar period made it possible to use large ore deposits which had formerly been commercially worthless.

[10] *Recent Developments in Steelmaking Practices, op. cit.*, VI–6.

[11] *Steel*, March 20, 1964, p. 34.

III. The Oxygen Converter

> **The inherent appeal of the converter principle as a high-speed refiner [of steel] . . . looms large. . . . With both economy and conservation demanding that a large fraction of total iron units be obtained from scrap, it is difficult to avoid the conclusion that the basic open-hearth furnace occupies top position among tonnage steel producers for any reason other than it truly belongs there. Those seeking to improve its performance, or that of other existing processes, are evidently in no immediate danger of technologic unemployment.[12]**

John Marsh, an American steelmaker reporting his observations on the European steel industry, made this statement in 1953, just after the first commercially successful oxygen converter had gone into operation. The European industry had been experimenting for a number of years with oxygen and oxygen-enriched air in converters working on the Bessemer principle. In 1952 the Vereinigte Oesterreichische Eisen- und Stahlwerke in Linz, Austria, put into operation a converter similar in design to the basic Bessemer; a water-cooled tube or lance blew a blast of pure gaseous oxygen onto the top of a bath of molten metal. Whether or not Mr. Marsh knew of this particular converter, he was aware of the general development. "If oxygen supply were the only factor to be considered," he said, "it would be hard to improve upon the Bessemer converter as a reaction vessel. . . ."

The U.S. steel industry's long familiarity with the Bessemer converter dates back to the mid-19th century when it was the first, and for many years the most widely used, of the modern steelmaking processes. The technique had its difficulties: The early types were adapted to acid ores and the best American ores were basic; Bessemer steel tended to absorb from the air blast, the essential feature of the process, undesirable amounts of dissolved nitrogen; and the reaction was very fast, giving rise to problems of quality control. American steelmakers avoided these difficulties by adopting the open hearth process, a larger scale, slower method. The open hearth became the preferred process, in spite of higher capital costs, with the development of low cost methods of operation, the ability to use large proportions of scrap, and the refinement of methods to control the chemical composition of the steel. From the 1930's on, Bessemer converters supplied only a small and steadily declining share of U.S. steel.

In the meantime, European steelmakers continued to develop the Bessemer process. They used basic linings,[13] achieved satisfactory quality levels, and found the smaller scale of operation well suited to their needs. When in the 1930's it became possible to buy mass-produced pure oxygen at low prices, they naturally followed up the decades-old suggestion of Sir Henry Bessemer that pure oxygen would refine steel in his converter more efficiently than ordinary air. When several plants tried oxygen and oxygen-enriched air in their basic Bessemer converters, they found that furnace linings wore away too fast. The converter at Linz successfully overcame this difficulty: Oxygen blown from above into the center of the mass of metal reacted as it should with the carbon in the bath, rather than with the refractory linings.

A second converter at Donawitz was soon started up, and the process was patented and named Linz-Donawitz (or L–D). The process spread fairly quickly, and competing designs incorporating the same basic principle became established. Early in 1954 a Canadian producer and later in the same year McLouth, a new steelmaking firm in the United States, installed top-blown oxygen converters.

For several years the established steel companies in the United States showed little interest in the process. In 1957, Jones & Laughlin became the second operator of oxygen converters. Kaiser followed in 1958, and Acme in 1959. By 1959, the 6th, 10th, 13th, and 25th ranking members[14] of the industry in order of tonnage produced were using the process. Between 1961 and 1965, 11 more steel companies, as well as 2 large steel mills owned by steel-using firms, either put the new process into operation or started constructing plants embodying it. By 1965, all but 3 of the 20 leading producers,[15] a group accounting for about 85 percent of the Nation's steel output, had installed or ordered oxygen converters for at least part of their production.

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[12] "Progress in Steelmaking Processes in America," by John S. Marsh, Research Engineer, Bethlehem Steel Corp., *Metal Progress*, January 1953, pp. 74–77.

[13] The Thomas converter, named after its inventor, is essentially a Bessemer converter with a basic lining capable of making steel from basic ores.

[14] Excluded are at least 2 and possibly 3 or 4 firms for which production figures were not published.

[15] Acme (later Interlake Iron and Steel) was 25th in 1959, but has since moved up into the top 20.

The order and timing of the introduction of oxygen converters, shown in table 4, invite some comment:

Oxygen steelmaking was invented and made commercially practicable outside the United States. Although news reports and technical papers describing the new process were published in this country, little research or experimental work here was reported, except by the companies that adopted the new process.

Firms which were industry leaders in output were by a considerable margin followers in adopting the new process. Every one of the first five firms, and several other early ones to commit themselves, were in one way or another different from conventional big steel firms.

McLouth, the first, was a new entrant in the industry. It had started steel fabrication in the 1930's, and in 1949 began operating scrap-charged electric furnaces in the booming Detroit area. The company outgrew the resources of the local scrap market, and decided to build a blast furnace on a deepwater site, buy ore and coke, and produce its own hot metal for steelmaking. Its oxygen converters, which went into operation toward the end of 1954, were a new and relatively small scale entry into ore-based steelmaking; since it already owned electric furnaces which it has continued to operate, the limited ability of the oxygen converters to use scrap was not a drawback.

Jones & Laughlin, the second firm to introduce oxygen converters, is one of the well-defined group of eight big steel companies consistently producing more than 3.5 million tons per year. However, as compared with four other firms in its 3.5–6 million ton bracket, it had a low rate both of growth and of return on investment in the late 1940's and 1950's. It had expanded its open hearth capacity less than any others of the big eight, and was one of only three out of the group to make any substantial investment in electric furnace capacity. Whether its managers did not share the strong faith of their competitors in the open hearth, or whether their poor profit showing impelled them to experimentation, the installation of two oxygen-converter shops, one in 1957 and one in 1961, fit in with the company's pattern of departure from the mainstream of Big Steel's business policy.

Six more of the innovators are firms in the 1- to 2-million-ton size group,[16] substantial producers but smaller by a large margin than the big eight.

TABLE 4. OXYGEN CONVERTERS IN THE UNITED STATES, SELECTED YEARS, 1954–66

Company	Year[1]																					
	1954		1957		1958		1959		1960		1961		1962		1963		1964		1965		1966	
1. Oxygen-converter capacity in operation																						
1. McLouth	540	0.26	----	----	1,385	0.68	----	----	2,000	0.98	----	----	----	----	----	----	----	----	----	----	----	----
2. Jones & Laughlin	----	----	950	0.15	----	----	----	----	----	----	2,850	.35	----	----	----	----	----	----	----	----	----	----
3. Kaiser	----	----	----	----	1,440	.49	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
4. Acme	----	----	----	----	----	----	450	0.42	----	----	----	----	----	----	----	----	----	----	----	----	----	----
5. Colorado	----	----	----	----	----	----	----	----	----	----	1,000	.35	----	----	----	----	----	----	----	----	----	----
6. National	----	----	----	----	----	----	----	----	----	----	----	----	2,500	0.36	----	----	----	----	----	----	----	----
7. Sharon	----	----	----	----	----	----	----	----	----	----	----	----	1,000	.51	----	----	----	----	----	----	----	----
8. Armco	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1,400	0.21	----	----	----	----	----	----
9. United States Steel	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1,500	.04	----	----	----	----	----	----
10. Ford Motor	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2,000	1.03	----	----	----	----
11. Pittsburgh	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1,500	.93	----	----	----	----
12. Bethlehem	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2,200	.10	----	----	----	----
13. Wheeling	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2,000	0.83	----	----
14. Republic	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3,000	.24	----	----
2. Oxygen-converter capacity planned																						
1. United States Steel																			6,000	.11	----	----
2. International Harvester																			1,200	1.00	----	----
3. Inland																			5,000	.39	----	----
4. Republic																			----	----	5,000	0.39
5. Bethlehem																			----	----	4,000	.17
6. National																			----	----	5,000	.71
7. Allegheny-Ludlum																			----	----	----	----
Total capacity installed September 1965																						27,040
Total capacity installed and planned through 1966																						[2] 36,040

NOTE: Each company's total oxygen converter capacity is shown for each year in which it started operating new converters. The first figure indicates total oxygen converter capacity in thousands of tons per year. The second figure is oxygen capacity divided by its 1960 total capacity. How much of the added capacity was expansion and how much replacement is not indicated for 1960 or later.

[1] No additions in 1955 or 1956.

[2] L–D Process Newsletter no. 24, Sept. 24, 1964, Kaiser Engineers Division of Kaiser Industries Corp., Oakland, Calif.; Letter from J. K. Stone, manager, Steel Plants Development, Kaiser Engineers Division, August 30, 1965; *Steel*, August 26, 1962, 54; March 19, 1962, pp.118–120; November 19, 1962, p. 116; November 16, 1964. p. 35; November 23, 1964, pp. 108–110; *The New York Times*, November 11, 1964, p. 61; *Directory of Iron and Steel Works in the United States and Canada*, New York: American Iron and Steel Institute, 1957 and 1960 eds.

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[16] See appendix. Kaiser and Colorado have occasionally produced more than 2 million tons, but not enough more, and not often enough to justify changing this convenient statistical boundary.

Kaiser, the third, and Colorado, the fifth, were geographically removed from the great central steelmaking regions. Sharon, the 7th, Pittsburgh, the 11th, and Wheeling, the 13th to adopt oxygen converters, are all located in the traditional Ohio Valley steel region. These five have had moderate to poor profit rates. Because they are all blast-furnace owners, electric furnaces are not particularly attractive to them in cost terms.

Number four, Acme, is just growing into the 1- to 2-million size group. The firm had an open hearth shop on the Ohio River, with fabricating and marketing facilities in Chicago. In 1959 it opened the smallest of the Nation's oxygen converter shops at its Chicago plant, with a hot metal supply produced in a cupola that melted steel scrap. Partly because the scrap melting operation did not provide all the hot metal the plant could use, and possibly partly because its cost was high, the company in 1964 merged with an operator of merchant blast furnaces in Chicago and elsewhere, becoming the Interlake Iron and Steel Corp. It then arranged to haul molten pig iron by common carrier railroad over the 15-mile route between blast furnace and converter.[17]

Of the remaining two firms in the 1- to 2-million ton group, Crucible is a multiplant producer of specialty steels with open hearth and electric furnaces. It has a choice between the oxygen converter and electric furnace as its mainstay, and has as yet announced no decision. Granite City, a relatively profitable open hearth operator, has announced plans for eventual replacement with oxygen converters.

This record justifies the generalization that firms in the 1- to 2-million-ton size range, producing about 10 percent of total U.S. output, were disproportionately represented among the innovators of the new process.

Following Jones & Laughlin, the big eight were represented by National in 1962, and Armco and United States Steel in 1963. Bethlehem, Republic, and Inland have scheduled startups in the 1964–66 period. Two "captive" mills owned by Ford Motor Co. and International Harvester will have replaced much of their open hearth capacity by 1966. Youngstown, currently the smallest of the big eight, is the only one of the group which has not announced plans to use the new process. Thus, the larger firms have been relatively late in making the decision.

A number of small firms remains to be accounted for. The American Iron and Steel Institute lists 70 or so steel furnace owners with capacities under 1 million tons per year. Twelve or 13 produce 100,000 tons or more, or a total of perhaps 7 percent of the national tonnage. Only one has shown any interest in the oxygen converter—Allegheny-Ludlum, which ranks 24th among steel producers. This firm is the only one to have built an *experimental* oxygen converter, and plans to build a moderate size shop to be supplied by a cupola for melting scrap.

With this exception, most companies in the under-1-million group are likely to find the electric furnace preferable to the oxygen converter. Few have the blast furnaces which are almost a necessity for low cost quantity production of hot metal. Furthermore, the small electric furnace shop suffers proportionately less from the economic disadvantages of small scale production than other types.

Why, then, in the face of growing apparent cost advantages for two rival processes, did the big steel companies concentrate on increasing the capacity of their open hearths? Why did oxygen converters appeal to the big firms in the midsixties and not in the fifties? Several possible explanations appear, although their relative importance is not clear.

During the 1950's, several technical problems remained to be solved in operating the oxygen converter. Because it emits quantities of dust and fumes, early users had to design hoods and gas-cleaning equipment to control them. The speed of reaction is so great that new sensing and measuring devices and new laboratory procedures were needed for control of quality. Selection of suitable refractory materials and scheduling of relining operations required study and experimentation. To the medium size firms it appeared to be good business to invest in this developmental work; to all but one of the large firms it did not.

Oxygen converters were frequently said to be too small to be of use to the large companies. This may simply reflect a natural but not entirely rational rule-of-thumb association between large size and efficiency—National, the most profitable and fastest-growing of the big eight, had the biggest furnaces and was steadily enlarging them. There is, however, another possible explanation. The 1964 Battelle study of steelmaking costs compared two plant designs, one with 48-ton converters and 500,000-ton capacity, the other with 180-ton converters and 1,500,000-ton capacity. It found that the larger plant would have substantially lower total costs per ton than the smaller.[18] If this is correct, the large companies may have given a practical demonstration of the saying traditionally ascribed to Andrew Carnegie that "pioneering don't pay." At any rate, the strategy of waiting until one's competitors have developed a process to the point where big bug-free, low cost plants can be built may be sound business. The plants actually designed for the large firms seem to fit this description.

In addition, in spite of comparisons based on expert estimates of costs by those outside the large companies, nobody knows, except perhaps the companies themselves, exactly how the marginal cost of additional output in enlarged and improved open hearths compared with the long run marginal cost of developing other kinds of furnaces. An entrepreneur making such a decision must, of course, estimate the burden of costs for each alternative, including some costs which cannot be precisely measured in advance. He may also add in an "uncertainty premium" as part of the cost of an unfamiliar course of action, to measure his firm's disinclination to choose a less rather than a more precisely predictable result. The steelmakers of the 1950's were thoroughly familiar with the open hearth. They owned many furnaces to which proven methods of expansion and improvement could be applied. Their uncertainty-premium estimates would surely weigh against the new types of furnace.

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[17] *Annual Report,* Interlake Iron and Steel Corp., 1964.

[18] *Recent Developments in Steelmaking Practices, op. cit.,* appendix tables A–17 through A–24.

If in the midfifties one of the big eight had put its capital and technical talent into oxygen converters either alone or in combination with electric furnaces, it would almost certainly have lowered its production cost per ton.[19] By waiting, they achieved a greater cost reduction, and perhaps risked less in developmental costs, but they lost some interim cost savings. Hindsight is cheaper than foresight, and even if we could follow the decisionmaking process step by step, it would be difficult to draw the line between purely objective cost comparison and natural bias in favor of the familiar.[20]

An industry like steel, in which a small number of firms control a large proportion of the productive capacity, may very well be far less receptive to technological change than an industry differently organized. The fewer the firms in a position to make and carry through decisions on technological change, the greater the possibility that all will, by coincidence, shun the burdens and uncertainties of change. In an industry where by and large things are going well, a kind of inertia may occur. Although they registered pro forma complaints about high costs and low profits, most of the steel companies had done fairly well during World War II, and in most of the decade following. It is natural enough not to monkey with a winning team; the open hearth was a familiar and an easily improvable technique; and an opportunity to lower costs may not, under these circumstances, have seemed sufficiently attractive to justify a change in the established ways of doing things.

The small group of firms which supply a large proportion of the demand for steel have in recent history followed business policies which have been described as oligopolistic. In price policy, the leading firms have for the most part avoided both overt collusion in the price setting and active use of price policy as a means of expanding their market shares. Steel prices have been generally published, infrequently changed, and apparently inflexible in reaction to short term changes in market conditions.[21]

If oligopolists accept a fairly inflexible price structure as a way of avoiding unwanted kinds of price competition, they may also accept a policy of relatively unchanging technology as a shelter from the "perennial gale of creative destruction" [22] implicit in actively striving for technological change. A firm considering an innovation may reason that if it tries to improve its competitive position in the industry, its competitors will react in such a way as to leave everybody about as well off as before.

Those firms that did initiate change were to some degree either striving to improve their position or fearful of losing their established competitive position in the industry. Consider again the first four users of oxygen converters. McLouth was a newcomer producing for the growing automobile industry. Acme was a small company bidding for a share of the expanding Chicago market. Kaiser was itself an innovation—a new integrated steel mill in a geographically isolated market. All three indicated a willingness to compete for improved positions. Their shares of the market were small enough so that they could hope to achieve substantial growth without making threatening incursions into the markets of the big companies.

The fourth pioneer, Jones & Laughlin, was one of the two slowest growing of the big eight, and less profitable than its most closely matched rivals. From this position, it might well have viewed cost-reducing innovations as a way of maintaining a threatened traditional position in the market, rather than of initiating a competitive move to improve it. And if the big eight did regard themselves as all being in the same boat, Jones & Laughlin had less than the others to lose by rocking it.

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[19] Firms which added open hearth capacity in the late 1950's are sure that they were choosing the lowest cost method then available. In retrospect, this is hard to believe. It may have been the best decision *at the time,* in view of the uncertainties of the new process. But the converters built in that period seem to be performing very well now, even in comparison with the most efficient and modern open hearths.

[20] Edwin Mansfield, "Size of Firm, Market Structure, and Innovation," *The Journal of Political Economy,* Dec. 1963, pp. 556–575.

[21] There is some disagreement among economists over the degree to which published and actual transaction prices correspond. Professor Stigler seems to suggest that in spite of the rigidity of published prices, steel is actually bought and sold in private transactions at prices that change, as they do in a competitive market, in response to changes in supply and demand. It is difficult to see how this can be proved or disproved; it is not what the industry says it does. George J. Stigler, "Administered Prices and Oligopolistic Inflation," *Journal of Business of the University of Chicago,* Jan. 1962, p. 1–13; M. A. Adelman, "Steel, Administered Prices and Inflation," *Quarterly Journal of Economics,* Feb. 1961, p. 16–40; W. Adams and J. B. Dirlam, "Steel Imports and Vertical Oligopoly Power," *The American Economic Review,* Sept. 1964, p. 626.

[22] Joseph A. Schumpeter, *Capitalism, Socialism and Democracy,* 3d ed., New York: Harper and Bros. 1947, p. 84.

IV. The Electric Furnace

The oxygen converter, the result of a fairly recent inventive process, is rapidly invading the field, and within a few years will occupy a large proportion of its potential market. The electric arc furnace is an old device, commercially used in Europe since 1900, and in the United States since 1906.[23] It was a steady producer of about 1 or 2 percent of the Nation's steel supply until the early 1940's, and has expanded its share to about 10 percent in recent years. This growth is a result not primarily of inventions or technological innovations, but of changing cost and market conditions which have led steel producers to make increasing use of a long available process.

Three factors have contributed to the growth of the electric process: (1) The electric furnace was used early to make small batches of steel whose composition needed to be precisely controlled. Until the 1940's its chief use was to produce alloy and stainless steels and special heats for castings. The expanding demand for alloy, stainless, and specialty steels has contributed to its increased use. (2) The price of scrap has been steadily declining in recent years, and has given electric furnaces, the only process that will operate efficiently on an all-scrap charge, a cost advantage. (3) Entry cost barriers are relatively small for electric furnace shops: the furnace itself is relatively inexpensive and, being independent of hot metal supplies, there is no need for investing in blast furnaces, coke ovens, and ore supplies. New electric furnace shops have been installed both to replace small open hearth plants and as new capacity.

A partial listing of plants which have added electric furnace capacity between 1948 and 1960 (see table 5) indicates the nature of the change.[24] A number of companies had no electric furnaces: Inland, National, and Youngstown of the big eight; Colorado, Granite City, Kaiser, Pittsburgh, and Wheeling of the medium size group, and 10 small open hearth operators.[25] Twenty-five firms below the million-ton annual production level were listed as electric furnace operators in 1960, and there have been a few newcomers since.

TABLE 5. STEELMAKING PLANTS WHICH ADDED SUBSTANTIALLY TO ELECTRIC FURNACE CAPACITY, 1949–60

[Thousands of tons per year]

Company	Location	Electric furnace capacity added	Open-hearth capacity retired[1]
1. Plants where open hearth capacity was replaced			
Bethlehem	Los Angeles	380	117
Bethlehem	Seattle	246	246
Atlantic	Atlanta	325	165
Carpenter[2]	Bridgeport	97	188
Armco	Sand Springs, Okla	140	54
Total		1,188	
2. Plants where electric furnace capacity was added to existing capacity			
Republic	South Chicago	824	
Armco	Houston	340	
Armco	Kansas City, Mo.	420	
Acme[3]	Newport, Ky	283	
Northwestern	Sterling, Ill	504	
Texas Steel	Fort Worth	170	
Total		2,541	
3. New electric furnace plants			
H. K. Porter[4]	Huntington, W. Va	84	
Southern Electric Steel	Birmingham	66	
Western Rolling Mills Division, Yuba Consolidated Industries.	Helena, Ariz	60	
Southwest Steel Rolling Mills.	Los Angeles	100	
Florida Steel	Tampa	51	
Ceco	Lemont, Ill	150	
Jessop[5]	Owensboro, Ky	183	
Eastern Stainless	Baltimore	73	
Merrit-Chapman-Scott[6]	Milton, Pa	110	
Cameron	Houston	59	
Le Tourneau	Longview, Tex	90	
Total		1,026	
Total, listed plants		4,755	
Other plants[7]		4,244	
Total increase 1948–60.		8,999	

Partial list of added electric furnace capacity since 1960:

1961:	Armco, Kansas City, Mo.	
	Mississippi Steel, Jackson	
1962:	Universal Cyclops, Bridgeville, Pa.	
	Universal-Cyclops, Mansfield, Ohio	100
1964:	Washington Steel, Washington, Pa	60
	Universal-Cyclops, Mansfield, Ohio	100
	Timken, Canton, Ohio	
	Roblin, Dunkirk, N.Y	140
	Latrobe, Latrobe, Pa.	
	Edgewater, Oakmont, Pa.	
	Carpenter, Reading, Pa.	

Planned:
Republic, Canton, Ohio
Florida Steel, Charlotte, N.C.
Colorado, Roebling, N.J.

[1] Open-hearth capacity was completely eliminated from the plant

[2] The Stanley Works to 1954: Northeastern Steel to 1957.

[3] Newport Steel to 1956; Interlake Iron and Steel from 1964.

[4] West Virginia Steel to 1956.

[5] Green River Steel to 1957.

[6] Boiardi Steel to 1951.

[7] This includes plant expansions where added capacity for the individua plant amounted to less than 50,000 tons for the period.

Sources: *Directory of Iron and Steel Works in the United States and Canada*, American Iron and Steel Institute, 1948 and 1960 eds.; "Partial listing of announced expansion plans," *Iron and Steel Engineer*, Jan. issues 1960–65.

In 1960, the big eight controlled 76 percent of the total steel-producing capacity, but only 42 percent of electric furnace capacity; the 20 largest controlled 88 percent of total capacity and 54 percent of electric capacity. So the electric furnace seems to be a more attractive investment for small firms. The process is also suited to plants away from steel-producing centers. The Pacific Coast States had 1,179,000 tons of capacity, the Southern States excluding Kentucky and Alabama had 1,198,000, and such unlikely places as Bridgeport, Conn., Sand Springs, Okla., and Kansas City, Mo. have substantial capacity. The process is favored by both large and small firms for alloy and stainless steels. Republic is building three 200-ton furnaces, with a guessed annual capacity of somewhat over half a million tons[26] in its alloy division at Canton, Ohio. Eastern Stainless, Jessop, Washington Steel, and Timken are among the smaller specialty steel producers which use electric furnaces.

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[23] *"The Making, Shaping and Treating of Steel," op. cit.*, p. 39.

[24] The firms included added 50,000 tons or more of capacity between 1948 and 1960.

[25] One of Colorado's smaller plants, and one open hearth plant of a small producer, have, since 1960, been converted to the electric process.

The cost estimates referred to earlier[27] indicate that at present low scrap prices, electric furnace shops of moderate size can produce steel at lower cost per ton than any open hearth or oxygen converter plant operating at the assumed hot metal costs. If these are reasonable estimates, a new entrant or an expanding steel producer would choose electric furnaces in preference to an integrated blast furnace and steelmaking plant except under unusual conditions.

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[26] The guess is probably conservative. It is based partly on the 1960 capacity ratings of the generally similar 200-ton furnaces at McLouth's Detroit plant and the 135-ton Republic furnaces at South Chicago.

[27] See table 3.

V. The Indian Summer of the Open Hearth

Although the large steel companies were slow in adopting the oxygen converter and content with less than their share of electric furnace capacity, they did devote resources to technological improvement in steelmaking. They worked hard and successfully on the stages of production preceding steelmaking; they discovered and developed new ore deposits; they invested in ore handling and processing, notably in equipment to convert the very large supply of low-grade taconite ore into an economically usable form; they also rebuilt blast furnaces, improving, enlarging, and modifying them to increase output; and they built a few new, large, technologically advanced furnaces. The last 20 years have seen a reduction in the number of working blast furnaces, an increase in their total output, and substantial improvements in engineering measures of efficiency.

Most of the increase in steel furnace capacity between 1948 and 1960 was made by enlarging and improving open hearth furnaces and adding new ones at existing plant locations.[28] Only two entirely new open hearth plants on new sites were built after 1948—United States Steel's Fairless Works in eastern Pennsylvania, and the Lone Star Steel plant at Lone Star, Tex. In many cases the annual capacity increase of a battery of furnaces was proportionately greater than the increase in heat size, indicating a larger number of heats per year. One of the most widely introduced operating improvements was the injection of oxygen into the open hearth furnace, which speeded the carbon removing reaction and lowered the cost per ton. Its success was often mentioned as a reason why firms invested in open hearth improvements instead of oxygen converters. The trend toward larger and more productive open hearth furnaces is shown in table 6.

The *Directory* listed in 1960 for the first time the oxygen producing facilities used by steel companies. United States Steel had oxygen at 13 of its 18 steelmaking shops, Bethlehem at 4 out of 8, Republic at 4 out of 8, National at both its plants, Jones & Laughlin at 3 of its 4, Armco at 3 of 8, and Youngstown at its 3 plants. All or most of the oxygen supplying facilities date from after World War II; their widespread installation no doubt explains why high cost or inadequate supply of oxygen was not considered an obstacle to the introduction of the oxygen converter.

TABLE 6. NUMBER AND CAPACITY OF OPEN HEARTH FURNACES OF LARGE STEEL COMPANIES, SELECTED YEARS, 1948–60

[Capacity in thousands of tons per year]

Company	1948			1951			1954			1957			1960		
	Number of furnaces	Capacity	Capacity per furnace	Number of furnaces	Capacity	Capacity per furnace	Number of furnaces	Capacity	Capacity per furnace	Number of furnaces	Capacity	Capacity per furnace	Number of furnaces	Capacity	Capacity per furnace
Total, United States	954	83,611	88	947	91,311	96	934	109,095	117	886	116,912	132	906	126,622	140
Total, 8 companies	686	66,693	97	689	73,235	106	667	87,517	131	662	93,856	142	667	103,038	155
United States Steel	312	28,663	92	313	30,966	99	266	35,952	135	260	36,921	142	259	39,877	154
Bethlehem	135	12,974	96	135	15,026	111	136	17,604	129	135	19,456	144	136	21,710	160
Republic	78	7,140	92	74	7,202	97	78	8,222	105	78	8,840	113	80	9,794	122
National	28	4,050	145	29	4,750	164	30	6,000	200	31	6,200	200	31	7,000	226
Jones & Laughlin	29	3,822	132	30	3,927	131	37	5,583	151	37	5,998	162	37	6,139	166
Armco	35	3,212	92	39	3,934	101	39	4,196	108	40	4,761	119	40	5,368	134
Inland	36	3,400	94	36	3,750	104	40	4,700	118	40	5,500	138	43	6,500	151
Youngstown	33	3,432	104	33	3,680	112	41	5,260	128	41	6,180	151	41	6,750	165

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[28] This account is based on a comparison of the 1948, 1951, 1954, 1957, and 1960 editions of the *Directory of Iron and Steel Works in the United States and Canada*, which reports number of furnaces, heat size, and annual capacity for each plant. In many cases, the number and type of furnaces in a given plant remains the same, but heat sizes, annual capacities, or both increase. It is not always clear whether this is due to operating changes, enlargement of existing furnaces, or replacement. It is probably safe to surmise that such capacity increases for the most part cost less per ton of capacity than new construction on a new site.

VI. Continuous and Pressure Casting

Two new methods of solidifying steel poured from the furnace have been introduced in the past few years in the United States. Using familiar basic principles, both cast the steel into shapes which make it possible to skip costly intermediate stages. Continuous casting has a history of some years development and commercial use in other countries; in the United States much, though not all, of the innovating initiative for both continuous and pressure casting has come from relatively small companies.

In a conventional steel mill, molten steel from the furnace is poured into an ingot mold and cast into an ingot, usually a large, roughly rectangular piece of steel. The ingot is removed from the mold and placed in a soaking pit, where it is stored and either kept at the right temperature or reheated in preparation for the rolling process. In due course it is rolled in a blooming mill into a billet, bloom, or slab[29] ready for further hot rolling. The continuous casting machine embodies a mold, open at both ends, into which the molten steel is poured. As it passes through the mold it is cooled, emerging as a continuous strand of the desired cross-section. The strand is cut into suitable lengths and is then ready for the hot-rolling mill. In pressure casting, the liquid steel is placed in a covered ladle, and air or gas under pressure forces it through a tube into a mold which shapes it, usually into a slab to be hot-rolled into a flat product. Both continuous and pressure casting thus eliminate the need for ingot molds, soaking pits, and blooming mills, and make possible considerable savings in capital cost, heat, and space. These processes also result in improved yield; a smaller proportion of the steel is lost because of quality defects between the furnace and the hot-rolling mill.

Table 7 lists continuous casting installations already in operation, planned, or mentioned as possibilities in the United States up to August 1965. Of the plants in operation, four belong to three of the big eight companies, one belongs to the medium group, and seven to firms under the 1-million-ton production rate. Of the last group, four are steel-fabricating or steel-using firms which have invested in small steelmaking shops with electric furnaces and continuous-casting machines. Two more firms, with plans apparently not yet in the construction stage, are in the same category. Installations are under construction or have been ordered by two large firms, one medium-sized, two small, and one captive steelmaker. The three most advanced plants using the pressure-casting technique for making slabs are a newly integrated stainless steelmaker, Washington Steel Co.,[30] a moderate size stainless steel producer, Eastern Stainless Steel,[31] and United States Steel's South Chicago plant.[32] Sharon Steel is reportedly planning to add a third oxygen converter, a vacuum degassing facility, and a pressure casting installation.[33]

The introduction of both continuous and pressure casting is quite recent. United States Steel's experimental continuous casting machine was first publicly described in 1962; Roanoke's machine was reported in commercial operation in 1963; and the rest of the presently working machines started in 1964 and 1965. Washington Steel announced its construction plans for pressure-casting slabs in 1962, and in a generally optimistic report in September 1964, described the process as not yet a proven commercial success.[34]

The continuous casting process has had a longer commercial history in other countries, and a good deal of news about it appeared in the American trade and technical press from the early 1950's on. The process, long used for nonferrous metals, was adapted for steel in Europe in 1948.[35] Its advantages were eloquently set forth in testimony before a Senate committee investigation in 1957,[36] and several American firms did experimental work on the process. It is puzzling why commercial application should have lagged so completely (even more than the oxygen converter) until the mid-sixties, and then begun with what appears to be an incipient rush.

Of some importance in the introduction of the process in this country was the existence, indeed almost the proliferation, of firms promoting the sale of patent rights, design, and construction services. The basic principle of continuous casting has apparently been around too long to be patentable, but some American firms have contracted with European patent holders to market

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[29] The processes are described in *The Making, Shaping and Treating of Steel, op. cit.*, ch. 18, 19, and 22. About three-quarters of the steel tonnage produced appears as hot rolled products. Part of the remainder is discarded as waste product and recycled as scrap, and part is processed in different ways.

[30] *Iron Age*, Jan. 4. 1962, p. 108; Sept. 24, 1964.

[31] *Steel*, Oct. 14, 1963, p. 51.

[32] *Steel*, June 17, 1963, p. 17; Feb. 22, 1965, p. 53.

[33] *Steel*, Apr. 6, 1964, p. 35.

[34] *Iron Age*, Sept. 24, 1964.

[35] *The Sources of Invention*, p. 276, 280.

[36] *Administered Prices*. Hearings before the subcommittee on Antitrust and Monopoly of the Committee on the Judiciary, U.S. Senate, 85th Cong., 1st sess., pursuant to S. Res. 57, 1957, pt. 3: Steel, pp. 676–712.

TABLE 7. CONTINUOUS CASTING OF STEEL IN THE UNITED STATES

Starting date	Company and location	Designer builder	Strand size, inches	Type of steel	Tons per hour	Tons per month, or year (1,000)	Remarks
1. Continuous casting machines in operation, 1965							
(1)	United States Steel, Gary, Ind.	United States Steel	8 x 30-48				Experimenting since 1932, announced 1962.
1964	Armco, Sand Springs, Okla.	DMB, Huber, Hunt & Nichols.	2⅞-4¼ [2]	Carbon, low all	75	15m	Electric furnaces, rebars, merchant bars.
1964	Armco, Butler, Pa	DMB, Huber, Hunt & Nichols.	6 x 6-5 x 60	Carbon, low all, stainless.	90		Billets, blooms, slabs, rounds.
1965	Copperweld, Warren, Ohio.	DMB, Birdsboro	3⅞-8 [2]	Low all	100	22.5m	Better quality, savings in cost.
1964	Florida Steel Co., Tampa, Fla.	Concast	Billet	Low all			Electric furnace, small.
1964	McLouth, Trenton, Mich.	Concast, Schloeman	8 x 36, 6 x 50	Carbon, stainless	90	250-300y	
1964	H. K. Porter, Birmingham, Ala.	Koppers	3 x 3, 6 x 6	Carbon, low all	18	17m	Electric furnace.
1965	National, Weirton, W. Va.	Concast, Blaw-Knox	To 9 x 40	Carbon	300	1500y	Oxygen converters, vacuum degassing.
1963	Roanoke Electric Steel, Roanoke, Va.	Babcock-Wilcox	4½ [2]	Carbon, low all	33		Electric furnace, rebars, and light angles.
1964	Roblin, Dunkirk, N.Y.	Koppers	2½-6 [2]	Carbon, low all	30	140y	Electric furnaces; save $20 per ton over buying billets;
1965	Soule Steel, Long Beach, Calif.	Concast	5 [2]	Carbon			Small.
1965	Wickwire Bros., Cortland, N.Y.	Cont. Cast., United Engineering.	2-4 to 32′ long [2]				Will handle total electric furnace capacity.
2. Continuous casting machines under construction or ordered, 1965							
(1)	Bethlehem, Bethlehem, Pa.	Olsson-Loftus-Western Gear.	6 [2]	Carbon			Experimental.
(1)	do	Hazelett	6 x 24				Experimental.
1966	Crucible, Midland, Pa.	DMB, Huber, Hunt & Nichols.	To 10 x 52	Stainless and specialty.		180y	
1966	International Harvester, South Chicago, Ill.	Koppers	Billet	Low all, carbon	120	500y	
(1)	Republic, Canton, Ohio.	Babcock-Wilcox	Billets 10 Slabs to 5 x 49	Alloy, stainless	100 + 200		Three 200-ton electric furnaces, vacuum degassing.
1966	United States Steel, Gary, Ind.	United States Steel	8 x 76	Carbon	150		Oxygen converters.
(1)	Oregon Steel Mills, Portland, Oreg.	Hazelett	Billets	Carbon			Electric furnaces, 1960 cap 150.
1966	Phoenix, Claymont, Del.	Concast	To 12 x 80	Carbon	150		Open hearth; savings of $29.05 per ton expected.
3. Plans announced or discussed in the trade press, 1965							
(1)	Ceco, Lemont, Ill						Will install continuous casting if new mill is built.
(1)	Temescal, Berkeley, Calif.						Pilot plant first, eventually 30y.
(1)	Rebel Steel, Dayton, Tenn.					175y	Planned in 1963, scrap-charged electric furnace, eventually beneficiate loca ore.
(1)	Jones & Laughlin, Aliquippa, Pa.		Billets, blooms	Carbon			

[1] Not known.
[2] Squared.

SOURCES: (1) = *Technical and Economic Analysis of the Impact of Recent Developments in Steelmaking Practices on the Supplying Industries*, Columbus, Ohio, Battelle Memorial Institute, Oct. 30, 1964, VI-24;
(2) = *Iron Age*, Aug. 5, 1965, p. 57.

United States Steel: (1); (2); *Annual Report*, 1962, 1964; *Steel*, May 11, 1964, pp. 34-35; Apr. 26, 1965, p. 35.
Bethlehem: (2); *Iron Age*, Feb. 6, 1964.
Armco: (1); (2); *Iron Age*, Apr. 4, 1963, p. 62; *Steel*, Apr. 1, 1963, p. 17; Oct. 25, 1963, p. 31; Nov. 18, 1963, p. 93; June 7, 1965, p. 136.
Copperweld: (1); (2); *Steel*, Aug. 19, 1963, p. 33; Apr. 12, 1965, p. 35.
Florida Steel: (1); (2); *Steel*, Dec. 9, 1963, p. 47; Dec 14, 1964, p. 71.
H. K. Porter: (1); (2); *Iron Age*, Mar. 21, 1963, p. 40; Sept. 12, 1963, p. 140; *Steel*, Mar. 25, 1963, p. 31; Sept. 14, 1964, pp. 144-147.
National: (1); (2); *Iron Age*, Mar. 26, 1964, p. 73; *Steel*, Mar. 23, 1964, p. 33.
Roanoke Electric Steel: (1); (2); *Iron Age*, Sept. 26, 1963, pp. 159-166; *Steel*, May 13, 1963, pp. 29-31.
Roblin: (1); (2); *Steel*, Mar. 20, 1964, p. 34; May 11, 1964, pp. 35-36; *Iron Age*, Dec. 10, 1964, pp. 37-40.
Soule Steel: (2); *Steel*, Apr. 6, 1964, p. 35; Dec. 14, 1964, p. 71.
Wickwire Bros.: (2); *Steel*, Mar. 29, 1965, p. 35.
Crucible: (1); (2); *Steel*, June 7, 1965, p. 136.
International Harvester: (1); *Iron Age*, Sept. 12, 1963, pp. 159-166; Sept. 3, 1964, p. 29.
Republic: (1); (2); *Annual Report*, 1964; *Steel*, Mar. 16, 1964.
Oregon Steel Mills: (2).
Phoenix: (2); *Iron Age*, Apr. 4, 1963, p. 62; *Steel*, Dec. 21, 1964, p. 32; Feb. 22, 1965, p. 10.
Ceco: *Steel*, Mar. 29, 1965, p. 35.
Temescal: *Steel*, Aug. 26, 1963, p. 33.
Rebel: *Steel*, June 10, 1963, pp. 31, 33.
Jones & Laughlin: (2); *Steel*, Sept. 18, 1962, pp. 86-91.

their patent rights and engineering skills in the United States. Probably the most ambitious of these arrangements is that of the American firm, Concast, Inc., established in 1963 by Concast A. G., of Zurich, Switzerland, I. A. Rossi, an engineer and executive of the Swiss firm, and National Steel Corp. It is an exclusive licensee in this country for the European firm's patents, which cover important design details and is the designer of National Steel's installation at Weirton, as well as several other projects. But United States Steel's own designs and those of a number of other American engineering firms are outside its patent control.

Another reason for the delay in introducing continuous casting in the United States was the lack of certain refinements in the process; improvements have only recently begun to make it acceptable to American firms. The first continuous casting machines in commercial operation were very tall: Not only was the mold vertical, but below it enough run-out space had to be provided so that the strand of steel could be cut to the desired length while still in the vertical position. A ladle of molten steel had to be hoisted 70 feet or more above the plant floor and the liquid poured through the mold, and if insufficiently cooled, the metal could break out in a flood from the bottom of the mold with catastrophic results. In recent models the strand is either bent to a horizontal position before cutting, or cast in a curved or slanting mold. The total height of the apparatus is much less and the pouring operation simpler and safer. Problems of product quality are being solved by current developmental work, notably the difficulties from the presence in certain types of steel of dissolved gases. These can be removed by vacuum degassing, with the molten steel treated between its removal from the furnace and the casting process.[37] Practical experience has, in addition, made it possible to cast larger shapes, particularly the wide and thick slabs required for continuous hot rolling mills producing flat-rolled products. With these problems on their way to being solved, a number of U.S. firms are finding it profitable to adopt the new technique for commercial production, and others to undertake experimental operations; with a few exceptions (notably United States Steel), the steel producers have until recently chosen to let others undertake the inital developmental work.

Continuous and pressure casting are entering the competitive structure of the industry at two points: A number of installations are in small electric furnace shops which mostly produce billets of small cross section, and a number are quite large—in Republic's large electric furnace shop at Canton, and in National's very large plant at Weirton combining oxygen converters, vacuum degassing, continuous casting of large slabs, and new rolling mills. If both these applications are successful enough to invite imitation, the process may contribute to the tendency for the market to divide between large operators of oxygen converters and electric furnace shops of various sizes. The simplicity and low capital cost of the process tends to lessen still further the entry barriers for small scale producers.

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[37] Vacuum degassing can be used in conjunction with any type of furnace or casting process, but the combinations described are common. *Recent Developments in Steelmaking Processes, op. cit.*, ch. V; *The Making, Shaping and Treating of Steel, op. cit.*, pp. 552–556.

VII. The New Steel Industry in the American Economy

Twenty years ago, it would have been reasonable to predict that the steel industry in the United States would continue on the course of development which the large firms have in fact followed until recently. The open hearth was the most efficient steelmaking device, and it could be made even more efficient by being enlarged, by expanding the supply of ore and hot metal, and by operating improvements its users would learn from experience. It fit well into the organization of the industry. Big blast furnaces and integrated ownership of ore supplies were the appropriate way of supplying metals. The then new continuous hot rolling mills converted steel into salable products on a scale matching that of the furnaces and blooming mills. The eight big companies with outputs of over 3 million tons clearly had command of a technology to match their size and market position, and it can surely have surprised nobody that as long as the open hearth, ingot mold, soaking pit, and blooming mill maintained their technological lead, the big eight would continue, as they have, to occupy a commanding position in the industry.

The oxygen converter and continuous casting machine quietly appeared as technological alternatives in the early 1950's. Their advantages were eloquently and, as later development have proved, reasonably accurately described in 1957 before the Subcommittee on Monopoly Power of the Senate Committee on the Judiciary. These hearings read like a sort of handbook for technological subversion of the steel industry. Taken together, the oxygen converter (then still a small scale device), the continuous casting machine, and the planetary rolling mill, described by T. Sendzimir,[38] presented the possibility of a small, flexible, low cost, integrated steel mill which could bring about the geographical and competitive deconcentration of the steel industry. This plan was not spelled out in so many words, but the proceedings make it quite clear, so that everybody from antitrust enforcers to promoters of regional development plans saw and were aroused by the possibilities. It is also evident that any steel company which had invested moderate amounts of capital in testing the innovations described and in developing those that showed promise would today be ahead of the typical member of the industry technologically, and quite possibly also competitively and in terms of profits.

The prospects of 1957 make interesting reading in 1965. The oxygen converter looked then like a small steelmaker's opportunity, and its early users so regarded it; it is now taking over as the central feature of large scale plants. The continuous casting machine still holds promise for the small firm, but is being planned for the new giant mills as well. The planetary mill has not achieved any substantial commercial success in this country. An obvious complement to the battery of new devices—a simple, cheap process of reducing iron ore to metal without blast furnace or coking coal—it is still viewed by the American industry as an interesting theoretical problem rather than an imminent commercial reality.

The technological assessment of the 1957 hearings underestimated two interconnected developments: The breakthroughs in ore processing and transportation, and improvements in blast-furnace efficiency which have converted hot metal from a scarce to a superabundant resource and contributed to the decline in scrap prices; and the unspectacular but steady growth in electric furnace production. These along with other developments can form the basis for a new prognosis of the effects of new steelmaking processes on the steel industry and the economy.

With at least as much prospect of success as the late Senator Kefauver's technological dreamers of 1957, we can predict that two kinds of steel mills will grow in numbers and success in the next few years. The large oxygen converter plants will almost certainly be producing at least half of the Nation's steel in a few years. Typical modern plants have a designed capacity of 2 to 3 million tons a year, using a pair of converters, one operating while the other is closed down for maintenance and relining. Just beyond the horizon of practicability are improvements in refractory materials and maintenance practices which will make it possible to have a battery of three converters, two operating while the third is shut down for relining. New plants are being laid out with space allowed for the third converter, and a few are being installed. In addition, operating reports from working shops indicate that at least some of them will produce more than their designed output after their breaking-in problems are solved.

Probably the smallest oxygen converter plants likely to be built from now on will have not much less than a 2-million-ton capacity.[39] Quite possibly the largest plants currently planned, of 3-million-ton capacity, will be outranked or expanded in the future. If new plants fall within this size range, and unless the demand for steel outpaces any current predictions, there is room in the U.S. market for no more than about 40 or 50 at the most, and perhaps as few as 20 such plants. All or most of the big eight, and some at least of the medium size firms, will probably form an oligopolistic group of oxygen converter operators at least as compact and as well protected by the economies of scale as in the industry's present structure. The large companies' present investment plans, their obvious advantages in raising capital on such a scale, and their existing hot metal supplies, rolling mills, and marketing organizations all point toward that result.

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[38] *Administered Prices, op. cit.*, p. 752.

[39] Since this was written, one of the smaller steel companies, Alan Wood, has announced plans to build two small oxygen converters. *Wall Street Journal*, Oct. 7, 1965, p. 15.

But the further this development goes, the more surely will steel scrap continue to be abundant and cheap. And the barriers to entry are considerably weakened if the Battelle research group and several new and expanding small electric furnace operators are right. Roblin Steel Corp. claims to be able to produce 120,000 or more tons of semifinished steel shapes in a $3 million plant supplied by the local scrap market. The large companies have traditionally used their ownership of ore as an instrument of market control; but the more efficiently they operate their ore properties, the cheaper will scrap become. They have maintained a relationship between semifinished and finished steel prices which has allowed limited opportunities for independent steel processors and fabricators who must buy semifinished shapes. But Washington Steel can pressure-cast stainless steel slabs from its own electric furnaces for less than the price it would pay in the market. The ancient and horrible devices of the would-be monopolist—price discrimination, merger, preemption of markets, and such—are less defensible and probably less effective than they once were. Almost as surely as there will be a small core of big companies, there will also be a surviving and perhaps modestly growing fringe of small ones.

The demand for steel has historically experienced cyclical, irregular, and emergency fluctuations of large amplitude and unpredictable timing, and the continuation of such fluctuations is one of the most surely predictable things about the steel industry. If the industry consists of competing contingents of large firms and small electric furnace operators, a strain of a new kind will be put on the market mechanism through which the demand for steel is related to supplies of hot metal and scrap. Integrated firms are likely to have a hot metal supply schedule which would give them a fairly strong incentive to keep their blast furnaces running at a steady pace. Their marginal cost for hot metal is probably below average cost whenever output drops substantially below the technologically optimum rate, and above when they try to push output to abnormally high levels. If they are sharing the market with independent electric furnace operators, they would have a competitive reason for lowering prices somewhat in the face of a decline in demand, so that they could make efficient use of their capacity by enlarging their share of a smaller total market demand. The electric producers would be squeezed, and would force down the price of scrap, with the result that less scrap would be brought to market. The oxygen converters would carry the base load, so to speak, and the electric furnaces the peak period fluctuations. Since much scrap is storable (as anybody who tries to dispose of a worn-out car will find out), and scrap dealers and processors probably have low fixed costs, this might be a rational enough approach to the problem of adjusting steel production to fluctuating demand.

But this implies some substantial departure from the pricing traditions of the steel industry. The bulk of the productive capacity has been controlled by a small number of large firms, which, since Andrew Carnegie's day, have sought fairly systematically and successfully to avoid short-term price changes in response to short-term demand changes. What price policies will they be able to follow if they are faced with a numerous competitive fringe?

They might cling to the tradition of price stability at the cost of cyclic instability of their own sales. Recessions of demand would, however, tend to drive the price of scrap down, thus giving the smaller companies lower costs and an incentive to expand their market shares. Faced with a rigid price list maintained by the large companies, the smaller firms could cut prices slightly in recessions, raise them slightly in booms, and stabilize their own output. The large firms might try, by whatever pricing policies they might devise and be allowed to use, to discipline the small firms into acceptance of price stability. But any substantial invasion of the small firms' market by the big ones would widen the gap between hot metal and scrap prices and increase the small firms' cost advantage. Probably the big firms, if they wish to avoid the development of a competitive fringe, had better try to acquire as large as possible a share of electric furnace capacity. But they are unlikely to be able to block small scale entry completely.

The new technological equilibrium toward which the steel industry is tending will settle down with some combination of oxygen converter and electric furnace capacity. The exact proportions are impossible to foresee, but the big oxygen converter plants are likely to provide half or more of the Nation's steel supply. There is also a strong possibility that the easy entry conditions of the electric furnace branch of the industry will improve the competitive position of smaller firms and tend to bring about a more flexible price policy.

NOTE ON SOURCES

Information has been compiled from the following sources, in some cases without specific reference being made:

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APPENDIX

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948–60

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	BE	EL		OH	BE	OX	EL		OH	BE	OX	EL
United States Steel																						
Clairton, Pa.	805	100	----	----	805	100	----	----	1,064	100	----	----	1,064	100	----	----	----	1,064	100	----	----	----
Duquesne, Pa.	1,743	92	----	8	1,943	93	----	7	1,462	74	----	26	1,521	86	----	----	14	1,741	83	----	----	17
Braddock, Pa.	1,753	100	----	----	2,080	100	----	----	2,179	100	----	----	2,179	100	----	----	----	2,529	100	----	----	----
Fairless Hills, Pa.	----	----	----	----	----	----	----	----	2,200	100	----	----	2,200	100	----	----	----	2,687	100	----	----	----
Youngstown, Ohio	2,344	67	33	----	2,484	68	32	----	2,943	73	27	----	2,943	73	27	----	----	2,712	80	20	----	----
Munhall, Pa.	4,279	100	----	----	4,866	100	----	----	3,570	100	----	----	4,043	100	----	----	----	4,598	100	----	----	----
Gary, Ind.	5,719	100	----	----	6,028	100	----	----	7,117	100	----	----	7,204	100	----	----	----	7,999	100	----	----	----
South Chicago, Ill.	4,525	83	11	6	4,675	84	11	5	5,470	87	9	3	5,441	88	9	----	3	5,589	95	2	----	3
Johnstown, Pa.	24	76	----	24	24	76	----	24	25	76	24	----	25	76	----	----	24	25	76	----	----	24
Donora, Pa.	842	100	----	----	900	100	----	----	1,015	100	----	----	1,015	100	----	----	----	1,015	100	----	----	----
Duluth, Minn.	690	100	----	----	918	100	----	----	973	100	----	----	973	100	----	----	----	973	100	----	----	----
Pittsburg, Calif.	363	100	----	----	365	100	----	----	391	100	----	----	380	100	----	----	----	380	100	----	----	----
McKeesport, Pa.	1,164	75	25	----	1,164	75	25	----	1,446	83	17	----	1,446	92	8	----	----	1,392	98	2	----	----
Lorain, Ohio	1,884	70	30	----	2,250	60	40	----	2,364	63	37	----	2,565	66	34	----	----	2,678	66	34	----	----
Ensley, Ala.	1,568	100	----	----	1,568	100	----	----	1,745	100	----	----	1,770	100	----	----	----	1,770	100	----	----	----
Fairfield, Ala.	1,282	100	----	----	1,352	100	----	----	2,086	100	----	----	2,227	100	----	----	----	2,227	100	----	----	----
Vandergrift, Pa.	500	100	----	----	480	100	----	----	275	100	----	----	0	----	----	----	----	----	----	----	----	----
Worcester, Mass.	250	100	----	----	250	100	----	----	287	100	----	----	287	100	----	----	----	0	----	----	----	----
Torrance, Calif.	208	97	----	3	214	94	----	6	224	95	----	5	222	100	----	----	----	237	100	----	----	----
Geneva, Utah	1,283	100	----	----	1,440	100	----	----	1,879	100	----	----	2,077	100	----	----	----	2,300	100	----	----	----
Total, United States Steel	31,266	92	7	1	33,869	91	7	2	38,715	93	6	1	39,582	93	6	----	1	41,916	95	4	----	1
Bethlehem																						
Bethlehem, Pa.	2,585	94	----	6	3,080	95	----	5	3,214	95	----	5	3,750	94	----	----	6	3,900	94	----	----	6
Steelton, Pa.	886	100	----	----	1,932	100	----	----	1,356	100	----	----	1,500	100	----	----	----	1,500	100	----	----	----
Sparrows Point, Md.	4,651	93	7	----	5,160	94	6	----	5,750	94	6	----	6,200	95	5	----	----	8,200	96	4	----	----
Lackawanna, N.Y.	3,120	100	----	----	3,920	100	----	----	5,000	100	----	----	5,720	100	----	----	----	6,000	100	----	----	----
Johnstown, Pa.	1,900	86	14	----	2,028	88	12	----	2,280	100	----	----	2,330	100	----	----	----	2,400	100	----	----	----
South San Francisco, Calif.	235	100	----	----	240	100	----	----	252	100	----	----	276	100	----	----	----	276	100	----	----	----
Los Angeles, Calif.	213	55	----	45	324	26	----	74	402	----	----	100	478	----	----	----	100	478	----	----	----	100
Seattle, Wash.	210	100	----	----	216	100	----	----	246	100	----	----	246	100	----	----	----	246	----	----	----	100
Total, Bethlehem	13,800	94	4	2	16,000	94	4	2	18,500	95	2	3	20,500	95	2	----	3	23,000	94	2	----	4
Republic																						
Youngstown, Ohio	2,150	67	33	----	2,130	69	31	----	2,142	69	31	----	2,189	70	30	----	----	2,129	75	25	----	----
Massillon, Ohio	610	100	----	----	610	100	----	----	620	100	----	----	620	100	----	----	----	680	100	----	----	----
Canton, Ohio	775	34	----	66	975	49	----	51	1,125	40	----	60	1,315	41	----	----	59	1,045	54	----	----	46
Cleveland, Ohio	1,500	100	----	----	1,637	100	----	----	2,572	100	----	----	2,860	100	----	----	----	3,490	100	----	----	----
Buffalo, N.Y.	830	100	----	----	870	100	----	----	882	100	----	----	882	100	----	----	----	900	100	----	----	----
South Chicago, Ill.	1,225	80	----	20	1,100	45	----	55	1,232	43	----	57	1,392	45	----	----	55	1,769	38	----	----	62
Gadsden, Ala.	650	100	----	----	745	100	----	----	789	100	----	----	789	100	----	----	----	1,209	65	----	----	35
Warren, Ohio	860	100	----	----	900	100	----	----	900	100	----	----	1,000	100	----	----	----	1,520	72	----	----	28
Total, Republic	8,600	83	8	9	8,967	80	8	12	10,262	80	6	13	11,047	80	6	----	14	12,742	77	4	----	19
3 giant firms	53,626	91	6	3	58,836	90	6	3	67,477	92	5	3	71,127	92	5	----	4	77,658	92	3	----	5
National																						
Weirton, W. Va.	1,950	100	----	----	2,300	100	----	----	2,600	100	----	----	3,000	100	----	----	----	3,300	100	----	----	----
Ecorse, Mich.	2,100	100	----	----	2,450	100	----	----	3,400	100	----	----	3,200	100	----	----	----	3,700	100	----	----	----
Total, National	4,050	100	----	----	4,750	100	----	----	6,000	100	----	----	6,200	100	----	----	----	7,000	100	----	----	----
Jones & Laughlin																						
Aliquippa, Pa.	1,764	67	33	----	1,764	67	33	----	1,764	67	33	----	1,900	68	32	----	----	2,428	48	16	36	----
Pittsburgh, Pa.	2,138	84	15	1	2,138	84	15	1	3,098	99	----	1	3,300	99	----	----	1	3,452	99	----	----	1
Cleveland, Ohio	840	100	----	----	945	100	----	----	1,305	100	----	----	1,400	100	----	----	----	1,945	79	----	----	21
Detroit, Mich.[1]	255	----	----	100	425	----	----	100	425	----	----	100	300	----	----	----	100	300	----	----	----	100
Total, Jones & Laughlin[2]	4,742	81	19	(*)	4,847	81	19	(*)	6,167	91	9	(*)	6,600	91	9	----	----	----	----	----	----	----
Total, Jones & Laughlin[3]	4,997	76	18	5	5,272	74	17	9	6,592	85	9	6	6,900	87	9	----	4	8,125	76	5	11	19
Armco																						
Ashland, Ky.	828	100	----	----	900	100	----	----	870	100	----	----	952	100	----	----	----	1,038	100	----	----	----
Butler, Pa.	432	100	----	----	474	86	----	14	499	86	----	14	547	86	----	----	14	559	87	----	----	13
Middletown, Ohio	972	94	----	6	1,540	85	----	15	1,697	86	----	14	2,249	87	----	----	13	2,700	89	----	----	11
Baltimore, Md.	95	----	----	100	102	----	----	100	102	----	----	100	102	----	----	----	100	108	----	----	----	100
Kansas City, Mo.	426	100	----	----	420	100	----	----	630	76	----	24	780	62	----	----	38	840	50	----	----	50
Sand Springs, Okla.	54	100	----	----	54	100	----	----	54	100	----	----	120	----	----	----	100	140	----	----	----	100

See footnotes at end of table.

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948-60—Continued

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	BE	EL		OH	BE	OX	EL		OH	BE	OX	EL
Houston, Tex.	560	100	----	----	840	100	----	----	1,050	86	----	14	1,200	75	----	----	25	1,365	75	----	----	25
Torrance, Calif.[4]	41	----	----	100	50	----	----	100	54	----	----	100	50	----	----	----	100	50	----	----	----	100
Total, Armco[5]	3,367	95	----	5	4,330	91	----	9	4,902	86	----	14	5,950	80	----	----	20	--------	----	----	----	----
Total, Armco[6]	3,408	94	----	6	4,380	90	----	10	4,952	85	----	15	6,000	79	----	----	21	6,800	79	----	----	21
Inland																						
Indiana Harbor, Ind.	3,400	100	----	----	3,750	100	----	----	4,700	100	----	----	5,500	100	----	----	----	6,500	100	----	----	----
Youngstown																						
Campbell, Ohio	1,452	83	17	----	1,542	87	13	----	1,662	86	14	----	1,728	97	3	----	----	1,800	100	----	----	----
Youngstown, Ohio	1,104	100	----	----	1,182	100	----	----	1,182	100	----	----	1,368	100	----	----	----	1,530	100	----	----	----
East Chicago, Ind.	1,446	77	23	----	1,526	78	22	----	2,656	100	----	----	3,144	100	----	----	----	3,420	100	----	----	----
Total, Youngstown	4,002	86	14	----	4,250	87	13	----	5,500	96	4	----	6,240	99	1	----	----	6,750	100	----	----	----
5 large firms[7]	19,561	92	8	(*)	21,927	91	7	2	27,269	94	3	3	30,490	94	2	----	4	--------	----	----	----	----
5 large firms[8]	19,867	90	7	3	22,352	90	7	3	27,744	93	3	4	30,840	93	2	----	5	35,178	90	1	3	6
First 8 firms[7]	73,187	91	7	1	80,763	91	6	3	94,746	92	4	3	101,619	92	4	----	4	--------	----	----	----	----
First 8 firms[8]	73,493	91	7	1	81,188	90	6	4	95,221	92	4	4	101,969	92	4	----	4	112,833	91	3	1	5
Wheeling																						
Steubenville, Ohio	1,073	100	----	----	1,440	100	----	----	2,130	73	27	----	2,200	74	26	----	----	2,400	76	24	----	----
Benwood, W. Va.	336	----	100	----	420	----	100	----	--------	----	----	----	--------	----	----	----	----	--------	----	----	----	----
Total, Wheeling	1,409	67	33	----	1,860	81	19	----	2,130	73	27	----	2,200	74	26	----	----	2,400	76	24	----	----
Colorado																						
Pueblo, Colo.	1,272	100	----	----	1,320	100	----	----	1,485	100	----	----	1,800	100	----	----	----	1,800	100	----	----	----
Tonawanda, N.Y.	180	100	----	----	240	100	----	----	252	100	----	----	295	100	----	----	----	295	100	----	----	----
Claymont, Del.[9]	460	100	----	----	468	100	----	----	495	100	----	----	500	100	----	----	----	507	100	----	----	----
Roebling, N.J.[9]	253	100	----	----	205	100	----	----	235	100	----	----	235	100	----	----	----	235	100	----	----	----
Total, Colorado[10]	1,452	100	----	----	1,560	100	----	----	--------	----	----	----	--------	----	----	----	----	--------	----	----	----	----
Total, Colorado[11]	2,165	100	----	----	2,233	100	----	----	2,467	100	----	----	2,830	100	----	----	----	2,837	100	----	----	----
Granite City																						
Granite City, Ill.	620	100	----	----	720	100	----	----	1,290	100	----	----	1,200	100	----	----	----	1,440	100	----	----	----
Pittsburgh																						
Monessen, Pa.	1,072	100	----	----	1,072	100	----	----	1,404	100	----	----	1,320	100	----	----	----	1,620	100	----	----	----
McLouth																						
Trenton, Mich.	--------	----	----	----	420	----	----	100	968	----	----	100	1,380	----	----	39	61	2,040	----	----	68	32
Kaiser																						
Fontana, Calif.	870	97	----	3	1,200	100	----	----	1,536	100	----	----	1,536	100	----	----	----	2,933	51	----	49	----
Crucible																						
Midland, Pa.	998	79	----	21	1,095	79	----	21	1,284	76	----	24	1,356	77	----	----	23	1,364	77	----	----	23
Syracuse, N.Y.	68	----	----	100	56	----	----	100	60	----	----	100	60	----	----	----	100	61	----	----	----	100
Harrison, N.J.	5	----	----	100	2	----	----	100	8	----	----	100	8	----	----	----	100	8	----	----	----	100
Pittsburgh, Pa.	183	79	----	21	--------	----	----	----	--------	----	----	----	--------	----	----	----	----	--------	----	----	----	----
Total, Crucible	1,254	75	----	25	1,153	75	----	25	1,351	72	----	28	1,423	73	----	----	27	1,433	73	----	----	27
Sharon																						
Farrell, Pa.	1,000	100	----	----	981	100	----	----	1,000	100	----	----	1,305	100	----	----	----	1,370	93	----	----	7
Lowellville, Ohio	572	87	----	13	460	87	----	13	550	87	----	13	593	88	----	----	12	593	88	----	----	12
Total, Sharon	1,572	95	----	5	1,441	96	----	4	1,550	95	----	5	1,898	96	----	----	4	1,963	91	----	----	9
Acme[12]																						
Newport, Ky.	413	100	----	----	705	59	----	41	709	53	----	47	608	53	----	----	47	608	53	----	----	47
Chicago, Ill.	--------	----	----	----	--------	----	----	----	--------	----	----	----	--------	----	----	----	----	452	----	----	100	----
Total, Acme	413	100	----	----	705	59	----	41	709	53	----	47	608	53	----	----	47	1,060	31	----	43	27
9 medium firms[13]	8,662	91	4	5	10,131	85	5	10	--------	----	----	----	--------	----	----	----	----	--------	----	----	----	----
9 medium firms[14]	9,375	84	4	12	10,803	86	4	10	13,405	83	4	13	14,895	81	4	4	11	17,726	70	3	18	8

See footnotes at end of table.

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948–60—Continued

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	BE	EL		OH	BE	OX	EL		OH	BE	OX	EL
Ford Motor																						
Dearborn, Mich	1,115	85	----	15	1,471	85	----	15	1,755	87	----	13	1,877	89	----	----	11	1,940	89	----	----	
International Harvester																						
South Chicago, Ill	900	100	----	----	900	100	----	----	1,000	100	----	----	1,200	100	----	----	----	1,200	100	----	----	----
Detroit [15]																						
Portsmouth, Ohio	720	100	----	----	1,290	100	----	----	1,290	100	----	----	1,500	100	----	----	----	1,000	100	----	----	----
20 firms [16]	85,603	----	----	----	95,652	----	----	----	112,671	----	----	----	121,341	----	----	----	----	144,699	----	----	----	----
Alan Wood																						
Ivy Rock, Pa	550	100	----	----	550	100	----	----	625	100	----	----	800	100	----	----	----	800	100	----	----	----
Alco Products																						
Chicago, Ill	78	100	----	----	78	100	----	----	78	100	----	----	0	----	----	----	----	----	----	----	----	----
Latrobe, Pa	103	100	----	----	103	100	----	----	103	100	----	----	105	98	----	----	2	109	97	----	----	3
Total, Alco	181	100	----	----	181	100	----	----	181	100	----	----	105	98	----	----	2	109	97	----	----	3
Allegheny-Ludlum																						
Brackenridge, Pa	431	60	----	40	767	34	----	66	747	32	----	68	747	42	----	----	58	795	41	----	----	59
Dunkirk, N.Y	33	----	----	100	33	----	----	100	33	----	----	100	33	----	----	----	100	33	----	----	----	100
Tonawanda, N.Y	5	----	----	100	5	----	----	100	5	----	----	100	5	----	----	----	100	4	----	----	----	100
Ferndale, Mich	3	----	----	100	3	----	----	100	3	----	----	100	3	----	----	----	100	4	----	----	----	100
Watervliet, N.Y	25	----	----	100	25	----	----	100	77	----	----	100	77	----	----	----	100	76	----	----	----	100
Total, Allegheny-Ludlum	496	54	----	46	832	31	----	69	864	28	----	72	864	36	----	----	64	912	36	----	----	64
Amer. Compressed Steel																						
Cincinnati, Ohio	0	----	----	----	0	----	----	----	22	----	----	100	22	----	----	----	100	22	----	----	----	100
Atlantic																						
Atlanta, Ga	165	100	----	----	188	100	----	----	300	63	----	37	400	31	----	----	69	325	----	----	----	100
Babcock & Wilcox																						
Beaver Falls, Pa	50	----	----	100	65	----	----	100	229	----	----	100	229	----	----	----	100	322	----	----	----	100
Baldwin																						
Burnham, Pa	149	100	----	----	149	100	----	----	170	100	----	----	170	100	----	----	----	189	90	----	----	10
Borg-Warner																						
New Castle, Ind	24	----	----	100	28	----	----	100	54	----	----	100	64	----	----	----	100	64	----	----	----	100
Chicago, Ill	----	----	----	----	----	----	----	----	100	----	----	100	100	----	----	----	100	118	----	----	----	100
Total, Borg-Warner	24	----	----	100	28	----	----	100	154	----	----	100	164	----	----	----	100	182	----	----	----	100
Braeburn Alloy																						
Braeburn, Pa	21	----	----	100	21	----	----	100	21	----	----	100	21	----	----	----	100	21	----	----	----	100
A. M. Byers																						
Ambridge, Pa	150	50	----	50	75	----	----	100	75	----	----	100	90	----	----	----	100	90	----	----	----	100
Cabot																						
Pampa, Tex	----	----	----	----	----	----	----	----	12	----	----	100	15	----	----	----	100	18	----	----	----	100
Cameron																						
Houston, Tex	----	----	----	----	----	----	----	----	59	----	----	100	59	----	----	----	100	59	----	----	----	100
Berkman																						
Toronto, O.[17]	136	100	----	----	121	100	----	----	136	100	----	----	135	100	----	----	----	136	100	----	----	----
Carpenter																						
Reading, Pa.[18]	75	----	----	100	81	----	----	100	86	----	----	100	87	----	----	----	100	88	----	----	----	100
Bridgeport, Conn.[18]	188	100	----	----	188	100	----	----	188	100	----	----	303	62	----	----	38	84	----	----	----	100
Total, Carpenter [19]	263	71	----	29	269	70	----	30	274	69	----	31	390	48	----	----	52	172	----	----	----	100

See footnotes at end of table.

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948-60—Continued

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	BE	EL		OH	BE	OX	EL		OH	BE	OX	EL
Ceco Steel Products																						
Lemont, Ill.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	150	----	----	----	100
Columbia Tool Steel																						
Chicago Heights, Ill.	7	----	----	100	7	----	----	100	7	----	----	100	7	----	----	----	100	7	----	----	----	100
Continental																						
Kokomo, Ind.	364	100	----	----	394	100	----	----	394	100	----	----	420	100	----	----	----	420	100	----	----	----
Copperweld																						
Warren, Ohio	450	----	----	100	554	----	----	100	618	----	----	100	660	----	----	----	100	660	----	----	----	100
Eastern Stainless																						
Baltimore, Md.	----	----	----	----	12	----	----	100	32	----	----	100	50	----	----	----	100	73	----	----	----	100
Edgewater																						
Oakmont, Pa.	140	100	----	----	146	100	----	----	90	100	----	----	118	100	----	----	----	118	100	----	----	----
Erie Forge																						
Erie, Pa.	209	100	----	----	85	100	----	----	234	100	----	----	234	100	----	----	----	284	82	----	----	18
A. Finkl & Sons																						
Chicago, Ill.	----	----	----	----	----	----	----	----	34	----	----	100	34	----	----	----	100	34	----	----	----	100
Firth, Sterling																						
McKeesport, Pa.	20	----	----	100	20	----	----	100	20	----	----	100	20	----	----	----	100	20	----	----	----	100
Florida Steel																						
Tampa, Fla.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	51	----	----	----	100
H. M. Harper																						
Morton Grove, Ill.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	12	----	----	----	100
Harsco																						
Harrisburg, Pa.	101	100	----	----	101	100	----	----	101	100	----	----	101	100	----	----	----	101	100	----	----	----
Heppenstall																						
Philadelphia [20]	524	82	----	18	417	78	----	22	353	51	----	49	163	62	----	----	39	175	----	----	----	100
Pittsburgh [20]	47	85	----	15	43	93	----	7	56	89	----	11	56	90	----	----	10	56	90	----	----	10
Total, Heppenstall [21]	571	82	----	18	460	79	----	21	409	56	----	44	219	46	----	----	54	231	22	----	----	78
Industrial Forge																						
Canton, Ohio	----	----	----	----	49	100	----	----	49	100	----	----	49	100	----	----	----	79	100	----	----	----
Isaacson Iron																						
Seattle, Wash.	104	----	----	100	102	----	----	100	102	----	----	100	102	----	----	----	100	102	----	----	----	100
Jessop																						
Washington, Pa.	50	----	----	100	42	----	----	100	33	----	----	100	36	----	----	----	100	36	----	----	----	100
Judson																						
Emeryville, Calif.	77	100	----	----	77	100	----	----	77	100	----	----	77	100	----	----	----	77	100	----	----	----
Keystone																						
Peoria, Ill.	302	100	----	----	325	100	----	----	425	100	----	----	450	100	----	----	----	600	100	----	----	----
Green River Steel [22]																						
Owensboro, Ky.	----	----	----	----	----	----	----	----	292	----	----	100	183	----	----	----	100	183	----	----	----	100
Kilby Steel [23]																						
Anniston, Ala.	74	73	----	27	34	----	----	100	34	----	----	100	34	----	----	----	100	34	----	----	----	100
Knoxville Iron																						
Knoxville, Tenn.	38	----	----	100	38	----	----	100	38	----	----	100	38	----	----	----	100	38	----	----	----	100

See footnotes at end of table.

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948–60—Continued

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	BE	EL		OH	BE	OX	EL		OH	BE	OX	EL
Laclede																						
Alton, Ill.	326	100	----	----	398	100	----	----	440	100	----	----	500	100	----	----	----	600	100	----	----	----
Latrobe Steel																						
Latrobe, Pa.	12	----	----	100	12	----	----	100	24	----	----	100	24	----	----	----	100	24	----	----	----	100
Le Tourneau																						
Longview, Tex.	-------	----	----	----	-------	----	----	----	83	----	----	100	83	----	----	----	100	90	----	----	----	100
Lone Star																						
Lone Star, Tex.	-------	----	----	----	-------	----	----	----	550	100	----	----	550	100	----	----	----	800	100	----	----	----
Lukens																						
Coatesville, Pa.	624	100	----	----	675	100	----	----	750	100	----	----	750	100	----	----	----	930	81	----	----	19
Merritt, Chapman & Scott [34]																						
Milton, Pa.	-------	----	----	----	51	----	----	100	43	----	----	100	90	----	----	----	100	110	----	----	----	100
Mesta Machine																						
West Homestead, Pa.	105	81	----	19	105	81	----	19	105	81	----	19	105	81	----	----	19	105	81	----	----	19
Mississippi Steel																						
Jackson, Miss.	-------	----	----	----	-------	----	----	----	-------	----	----	----	45	----	----	----	100	45	----	----	----	100
National Forge																						
Irvine, Pa.	25	----	----	100	25	----	----	100	25	----	----	100	25	----	----	----	100	25	----	----	----	100
Northwestern																						
Sterling, Ill.	321	----	----	100	321	----	----	100	825	----	----	100	825	----	----	----	100	825	----	----	----	100
Oregon Steel Mills																						
Portland, Oreg.	66	----	----	100	120	----	----	100	110	----	----	100	110	----	----	----	100	150	----	----	----	100
Pacific States Steel																						
Niles, Calif.	95	100	----	----	231	100	----	----	182	100	----	----	216	100	----	----	----	265	100	----	----	----
Pencoyd																						
Philadelphia, Pa.	-------	----	----	----	-------	----	----	----	-------	----	----	----	-------	----	----	----	----	16	----	----	----	100
Phoenix																						
Phoenixville, Pa.[35]	231	100	----	----	431	100	----	----	432	100	----	----	360	100	----	----	----	360	100	----	----	----
Harrisburg, Pa.[36]	288	100	----	----	406	89	----	11	406	89	----	11	487	92	----	----	8	487	92	----	----	8
Total, Phoenix	519	100	----	----	837	95	----	5	838	95	----	5	847	95	----	----	5	847	95	----	----	5
H. K. Porter																						
Aliquippa, Pa.[37]	10	----	----	100	10	----	----	100	10	----	----	100	10	----	----	----	100	10	----	----	----	100
Birmingham, Ala.[38]	60	----	----	100	60	----	----	100	68	----	----	100	115	----	----	----	100	150	----	----	----	100
Huntington, W. Va.[39]	-------	----	----	----	-------	----	----	----	68	----	----	100	84	----	----	----	100	117	----	----	----	100
Total, H. K. Porter	70	----	----	100	70	----	----	100	146	----	----	100	209	----	----	----	100	277	----	----	----	100
Simonds Saw																						
Lockport, N.Y.	22	----	----	100	22	----	----	100	22	----	----	100	22	----	----	----	100	22	----	----	----	100
Southern Electric Steel																						
Birmingham, Ala.	-------	----	----	----	-------	----	----	----	-------	----	----	----	66	----	----	----	100	66	----	----	----	100
Southwest Steel Rolling Mills																						
Los Angeles, Calif.	-------	----	----	----	36	----	----	100	45	----	----	100	45	----	----	----	100	45	----	----	----	100
Texas Steel																						
Fort Worth, Tex.	22	----	----	100	22	----	----	100	36	----	----	100	70	----	----	----	100	192	----	----	----	100
Timken																						
Canton, Ohio	547	37	----	63	547	37	----	63	648	----	----	100	700	----	----	----	100	700	----	----	----	100

See footnotes at end of table.

STEELMAKING PLANTS IN THE UNITED STATES, BY ANNUAL CAPACITY AND PERCENT DISTRIBUTION BY TYPE OF FURNACE, SELECTED YEARS, 1948-60—Continued

[Capacity in millions of tons]

Company and location	1948				1951				1954				1957					1960				
	Capacity	Percent			Capacity	Percent			Capacity	Percent			Capacity	Percent				Capacity	Percent			
		OH	BE	EL		OH	BE	EL		OH	EB	EL		OH	BE	OX	EL		OH	BE	OX	EL
Union Electric Steel																						
Carnegie, Pa.	21	----	----	100	27	----	----	100	27	----	----	100	27	----	----	----	100	27	----	----	----	100
Universal-Cyclops																						
Bridgeville, Pa.	54	----	----	100	54	----	----	100	70	----	----	100	70	----	----	----	100	77	----	----	----	100
Mansfield, Ohio [30]	370	100	----	----	390	100	----	----	455	100	----	----	500	100	----	----	----	500	100	----	----	----
Total, Universal-Cyclops	428	87	13	----	444	86	----	12	525	87	----	13	570	86	----	----	14	577	86	----	----	14
Vanadium-Alloys																						
Latrobe, Pa.	12	----	----	100	12	----	----	100	12	----	----	100	10	----	----	----	100	12	----	----	----	100
Monaca, Pa.	7	----	----	100	7	----	----	100	30	----	----	100	32	----	----	----	100	30	----	----	----	100
Total, Vanadium-Alloys	19	----	----	100	19	----	----	100	42	----	----	100	42	----	----	----	100	42	----	----	----	100
Washburn Wire																						
Phillipsdale, R.I.	60	100	----	----	93	100	----	----	93	100	----	----	93	100	----	----	----	93	100	----	----	----
Wickwire Bros.																						
Cortland, N.Y.	38	100	----	----	0	----	----	----	20	----	----	100	30	----	----	----	100	29	----	----	----	100
Roanoke Electric Steel																						
Roanoke, Va.	----	----	----	----	----	----	----	----	----	----	----	----	24	----	----	----	100	25	----	----	----	100
Western Rolling Mills																						
Helena, Ariz.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	60	----	----	----	100
Total, United States	94,233	89	6	6	104,503	87	5	7	124,330	88	4	8	133,459	88	3	(*)	9	148,571	85	2	3	10

---

[1] Jones & Laughlin merged with Rotary Electric Steel in 1957.
[2] Excluding Rotary.
[3] Including Rotary.
[4] Armco acquired National Supply Co. between 1957 and 1960.
[5] Excluding National Supply, Torrance.
[6] Including National Supply, Torrance.
[7] Excluding Rotary and National Supply.
[8] Including Rotary and National Supply.
[9] Colorado acquired Worth Steel Co., Claymont, Del., in 1951 and J. A. Roebling's Sons, Roebling, N.J., in 1952.
[10] Excluding Worth and Roebling.
[11] Including Worth and Roebling.
[12] Newport Steel Co. to 1954; Interlake Iron and Steel from 1964.
[13] Excluding Worth and Roebling.
[14] Including Worth and Roebling.
[15] Portsmouth Steel Co. to 1949.
[16] All firms with 1 million tons capacity or more in 1960. For the years before 1960, firms later acquired by these firms are included.
[17] Folansbee Steel in 1948, Ohio River Steel in 1951.
[18] Bridgeport owned by The Stanley Works to 1954, Northeastern Stee Co. to 1957.
[19] Includes Bridgeport plant.
[20] Philadelphia plant owned by the Midvale Corporation to 1954.
[21] Includes Philadelphia plant.
[22] Acquired by Jessop, 1957.
[23] J. I. Case Co. to 1948.
[24] Boiardi Steel Co. to 1951.
[25] Barium Steel, 1957.
[26] Central Iron & Steel to 1957.
[27] Vulcan Crucible Steel to 1957.
[28] Connors Steel to 1953.
[29] West Virginia Steel to 1956.
[30] Empire Steel to 1958.
*Less than 0.5 percent.

Symbols: OH=Open hearth method.
BE=Bessemer converter method.
OX=Basic oxygen process method.
EL=Electric furnace method.

Part 3

SKILL REQUIREMENTS

THE RELATIONSHIP OF INCREASING AUTOMATION AND SKILL REQUIREMENTS

Prepared for the Commission
by
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Boston, Mass.

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The Relationship of Increasing Automation to Skill Requirements[1]

Introduction

One of the most critical and emotional issues of automation[2] is its effect on the nature of individual jobs as well as on the composition of the work force. We face national, local, and personal problems arising out of answers to such questions as:

> Does automatic production machinery require extensive training of the factory work force or replacement with people of higher skills?
>
> Will the average worker become unemployable due to lack of skill sufficient to deal with the growth of automation?
>
> Will maintenance requirements cause an insuperable training problem; and will they change the composition of the work force to one largely composed of maintenance men (and other highly skilled workers in supporting tasks)?

Those who have followed automation literature, congressional hearings, collective bargaining actions, and speeches on automation by managers, union leaders, politicians, consultants, sociologists, labor economists, and other academic specialists, know that there have been many eloquent and passionate claims on the above issues. Unfortunately, they generally are supported only by emotion, by "opinion" surveys, or by macrostatistics on the composition of industry or national work forces. In this last case, the inference is that whatever changes appear in work force proportions is largely due to automatic machinery—a dubious oversimplification. Still, there is an understandable projection that the skilled worker manning a machine tool will require even more skill as equipment becomes more automatic and complex.

In simple terms, the popular and apparently logical reasoning runs like this:

> Automation results in machinery of a more automatic nature directed by highly automatic controls. Both machinery and control devices are complex and sophisticated in their actions, and must be carefully adjusted and attended to achieve performance requirements. Therefore, employees manning and servicing this equipment need a higher degree of understanding and education. They will require additional training, higher types of skills, and even new levels of education. Intense concentration seems to be necessary. Thus, the job content of individual tasks associated with the new machinery will require more skill. An upgrading effect is obvious.
>
> Moving beyond the individual and looking at the factory as a whole, it becomes clear that the payroll will have to include more skilled and fewer unskilled persons. Furthermore, automatic machinery will eliminate many low-skill workers and put relatively highly skilled operators in their places. Meanwhile, the maintenance force will have to be expanded, at least in terms of percentage. A more highly skilled factory work force is, therefore, inevitable and essential. The same reasoning applies to white-collar workers associated with mechanization of the office, especially the computer.

This common train of thought, so logical and persuasive, leads to two general points of view. First, many managers, machinery manufacturers, engineers, and automation enthusiasts have held that upgrading is the blessing of automation. It will relieve labor of drudgery and of monotonous, repetitive work. The superior levels of education and training required will deserve, and will command higher prestige and pay for the worker. Automation should be welcomed because it will upgrade labor and create higher caliber and more dignified, satisfying, and valuable social and economic worker tasks.

The other point of view so vehemently expressed by many labor leaders but also supported by some social scientists, popular writers, and politicians originates from the same premises and concludes, "exactly so!" Spokesmen then proceed to a logical and alarming end: Not only will the average worker be displaced by the higher productivity of the automatic equipment; he will be barred from the plant because he lacks the education, training, and skill necessary to hold automated jobs. The automated plant thus becomes a "technological lockout" for the common man. Expensive retraining efforts and legislation to soften the blow to labor are, therefore, an urgent social necessity. Clearly, workers capable of manning this sophisticated equipment deserve higher pay because of their greater skill and increased responsibility.

---

[1] This theory was first presented in my research study, *Automation and Management* (Division of Research, Harvard Business School, Boston, 1958). A rational, consistent relationship linking "mechanization" and "skill" proved to be of such broad interest that a condensation was presented as, "Does Automation Raise Skill Requirements?" in the *Harvard Business Review*, July–Aug. 1958. Subsequently, I was invited to present the theory before many labor and management audiences throughout the world. This paper represents an up-dated version of all my former thoughts on this topic, testing them against the actual experiences in highly automatic factories during the last 8 years. To my knowledge, this is still the only theory interlinking machine evolution and worker contribution.

[2] I use "automation" in its original, basic sense, as defined by its originator, D. S. Harder, of meaning highly automatic and integrated machinery systems in the factory. The analysis and issues raised, however, apply equally to mechanization in the office.

If these sweeping generalizations are not on firm ground, we stand to make some serious mistakes. It is important that we understand how man-machine relationships are changing, since we are basing educational plans, retraining programs, union agreements, wage policies, and social legislation and even attitudes upon this relationship.

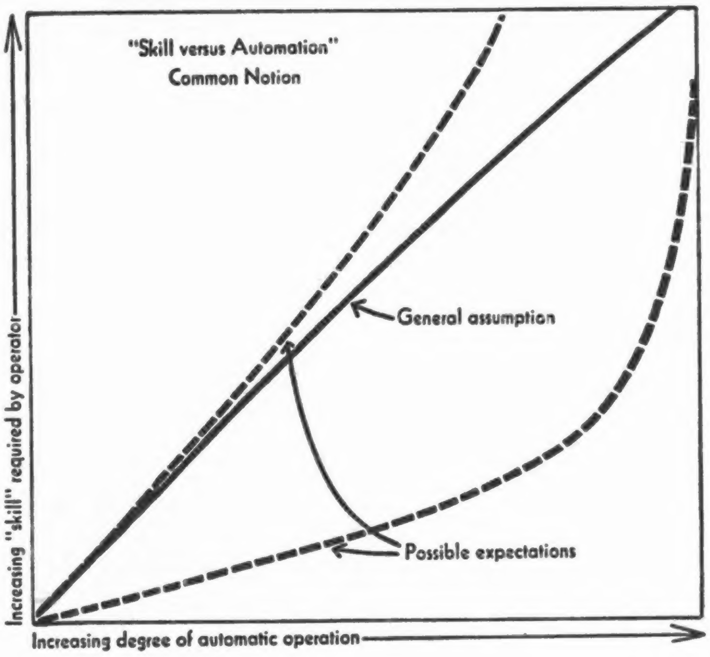
What are the underlying assumptions as to why mechanization will upgrade the work force? There seem to be at least six basic notions:

1. That automatic machinery requires higher degrees of worker skill and/or training than does conventional equipment.
2. That automatic machinery requires more maintenance attention and/or higher types of maintenance skills than conventional equipment.
3. That more engineers and technicians are required to design, build, install, and/or operate highly automatic machinery.
4. That the new machinery is introduced in such quantities and at such short intervals that the impact is significant.
5. That the average work force cannot meet the demands of new equipment, at least without elaborate retraining.
6. That conditions in the company are such that a new displacement of unskilled workers in favor of skilled workers will occur at the time automation is installed.

It is the thesis of this paper that we should examine precisely what machinery evolution toward automation does to job content. Then we can decide what kind of retraining, education, and wage adjustments are necessary.

During the several years that I spent in field research on managerial problems in so-called automated plants and in exploring automation with industrialists, government personnel, social scientists, and other researchers, I was startled to find that the upgrading effect had not occurred to anywhere near the extent that is often assumed.[3] On the contrary, there was more evidence that automation had reduced the skill requirements of the operating work force, and occasionally of the entire factory force, including the maintenance organization.

Exhibit 1.—How Demands on the Worker Are Commonly Assumed To Increase With Automation



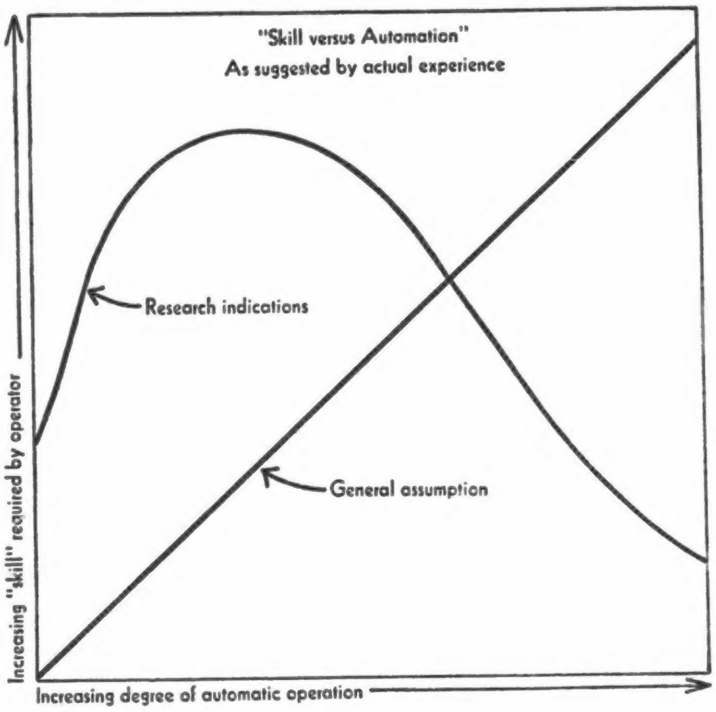
I found frequent instances in which management's stated belief that automation had required a higher caliber of work force skill was refuted when the facts were explored. The training time for some key jobs was reduced after automation to a fraction of the former figure. Here, then, was a series of results which directly opposed common automation claims (see exhibit 1). They certainly challenged the truth, or at least the universal applicability of the assumption that the automated factory requires a more highly skilled work force than the conventional one. This is not to deny that there were examples of skill increases required by automation; but it did seem that their frequency and importance were exaggerated.

A significant conclusion which developed out of the theory about to be described is that automation does not inevitably mean lack of opportunity for the unskilled worker. On the contrary, automated machinery tends to require less operator skill after certain levels of mechanization are achieved. Exhibit 2 roughly interprets this hypothesis. It seems that the average worker will master different jobs more quickly and easily when using highly automatic machinery. Many so-called key jobs, currently requiring long experience and training, will be reduced to easily learned, machine-tending jobs. To understand how this can be, let us examine the demands machinery makes on the worker. We will consider a general hypothetical condition, and freely admit that exceptions will have to be considered in adapting this theory to practice.

---

[3] For results of this research, see Bright, *Automation and Management, op. cit.*

Exhibit 2.—How Demands on the Worker Increase With Automation as Indicated by Field Studies



The "Skilled Worker"

Perhaps the best way to start is by asking what kinds of contributions the worker makes to production tasks. A general list of things for which he receives compensation might include:

1. *Physical effort*—the expenditure of energy through bodily movement either to manipulate materials and tools or to control something in the environment.
2. *Mental effort*—the use of mental powers to sense and analyze job requirements and to decide and direct the necessary response action. This contribution also implies the need for attention and concentration, and hence mental strain and fatigue.
3. *Manipulative skill*—the employment of a specialized physical dexterity, presumably acquired only by training and/or practice, or possibly by unique physical aptitudes.
4. *General ability*—a loose term implying understanding and competence in a task not too susceptible to learning through mechanical rote or formal analysis. This might be thought of as similar to competence in an art—the development of physical and mental aptitudes through practice and/or study.
5. *Education*—the knowledge of and competence in the use of a formally organized body of theory and fact apparently required by the task.
6. *Experience*—elements of ability, comprehension, and judgment that are only acquired by practice at the task.
7. *Exposure to hazards*—the extraordinary working conditions in which the operator's own safety or health is jeopardized to some degree.
8. *Undesirable job conditions*—the unpleasant or uncomfortable environmental conditions or work arrangements, either physical or social, that require special consideration.
9. *Responsibility*—the extent to which the operator controls safety, product quality, or productivity of the activity with respect to persons, equipment, and/or materials.
10. *Decisionmaking*—the extent to which the worker must or can make judgments that have a significant effect on successful performance.
11. *Productivity*—the extent to which the worker increases output above an expected norm by contributing exceptional effort, skill, knowledge, or ability.
12. *Seniority*—the mechanistic measurement of service time that presumably reflects greater contribution by the worker through some of the factors above. Perhaps this also might be thought of as a reward for loyalty.

While this list might be challenged in detail, its concept seems valid: that is, there are numerous different kinds of physical and mental activities which the worker may or must contribute to an economic task. (That there is room for disagreement on these activities or my suggested definitions also shows that the phrase "skilled worker" has a highly subjective connotation. Certainly "skilled worker" is not used consistently by many of us, nor uniformly by industry or labor.)

It is immediately apparent that not all of these demands or contributions are equally important in a given task, nor are they of a constant relative importance from one production task to another. And it is even more strikingly evident that as the character of mechanization applied to a given job is changed, the contributions of the operator will probably change in some ways. In even a simple activity the worker's contribution can vary depending on the equipment he uses. Consider, for instance, the physical effort of a construction worker using wheelbarrow and shovel versus the skill, mental effort, and experience required to use a bulldozer on the same job.

Therefore, to understand how automation affects work force skills, we must consider how each of the demands in any given job is affected by increasing degrees of mechanization and automatic control. How is job content altered by this increasing sophistication of a mechanism's performance?

Qualities of Mechanization and Effect on Job Content

Mechanization is not an equivalent thing in every production system.[4] One production line is "more mechanized" than another. Wherein lies the difference? Part of the explanation is that mechanization has at least three fundamental qualities or dimensions:

1. *Span*—the extent to which mechanization spreads across a sequence of production events.
2. *Level*—the degree of mechanical accomplishment by which a given production action is performed (thus reflecting, in part, in the fact that automatic control leads to increasing sophistication in the response of the machinery to environmental conditions).
3. *Penetration*—the extent to which secondary and tertiary production tasks, such as lubrication, setup, adjustment, and repair, are mechanized.

The concept of *levels of mechanization* is based on the assumption that there are different degrees of mechanical accomplishment in machinery. We can sense this by asking: In what way does a machine supplement man's muscles, mental processes, judgment, and degree of control? Then we can examine the characteristics of mechanical performance by analyzing how tools refine and supplement man's abilities. This analysis can be arranged and related, as in exhibit 3. A distinct evolution is apparent in these levels:

> First, there is the substitution of mechanical power for manual effort, which takes some burden from the worker (after level 2).
>
> Then, as increasing degrees of fixed control yield the desired machine action, the worker does less and less guidance of the tool (levels 5–8).
>
> As the ability to measure is added to the machine, a portion of the control decision information is mechanically obtained for the operator (after level 8).
>
> As the machine is given still higher degrees of automation, more and more of the decisionmaking and appropriate follow-up action is performed mechanically (i.e., by the mechanisms). For instance, as the selection of necessary machine speeds, feeds, temperature control, and so on is mechanized, further "decisionmaking," "judgment," "experience," and even "alertness" demands are lifted from the worker (levels 12–14).
>
> Finally, the machine is given the power of "self-correction" to a minor, and then to a greater, degree (levels 15–17), until the need to adjust the machine has been completely removed from the worker.

EXHIBIT 3.—LEVELS OF MECHANIZATION AND THEIR RELATIONSHIP TO POWER AND CONTROL SOURCES

INITIATING CONTROL SOURCE	TYPE OF MACHINE RESPONSE		POWER SOURCE	LEVEL NUMBER	LEVEL OF MECHANIZATION
FROM A VARIABLE IN THE ENVIRONMENT	RESPONDS WITH ACTION	MODIFIES OWN ACTION OVER A WIDE RANGE OF VARIATION	MECHANICAL (NONMANUAL)	17	ANTICIPATES ACTION REQUIRED AND ADJUSTS TO PROVIDE IT.
				16	CORRECTS PERFORMANCE WHILE OPERATING.
				15	CORRECTS PERFORMANCE AFTER OPERATING.
		SELECTS FROM A LIMITED RANGE OF POSSIBLE PRE-FIXED ACTIONS		14	IDENTIFIES AND SELECTS APPROPRIATE SET OF ACTIONS.
				13	SEGREGATES OR REJECTS ACCORDING TO MEASUREMENT.
				12	CHANGES SPEED, POSITION, DIRECTION ACCORDING TO MEASUREMENT SIGNAL.
	RESPONDS WITH SIGNAL			11	RECORDS PERFORMANCE.
				10	SIGNALS PRESELECTED VALUES OF MEASUREMENT (INCLUDES ERROR DETECTION).
				9	MEASURES CHARACTERISTIC OF WORK.
FROM A CONTROL MECHANISM THAT DIRECTS A PREDETERMINED PATTERN OF ACTION	FIXED WITHIN THE MACHINE			8	ACTUATED BY INTRODUCTION OF WORK PIECE OR MATERIAL.
				7	POWER TOOL SYSTEM, REMOTE CONTROLLED.
				6	POWER TOOL, PROGRAM CONTROL (SEQUENCE OF FIXED FUNCTIONS).
				5	POWER TOOL, FIXED CYCLE (SINGLE FUNCTION).
FROM MAN	VARIABLE			4	POWER TOOL, HAND CONTROL.
				3	POWERED HAND TOOL.
			MANUAL	2	HAND TOOL.
				1	HAND.

Courtesy of the *Harvard Business Review*.

One need not accept this particular classification of "levels" to confirm the fundamental point: that successive advances in automatic capability generally reduce operator duties and hence contributions. It would seem from this concept that the more automatic the machine, the less the operator of the machine has to do.[5]

But earlier we recognized that the worker's contribution on the job embraces more than "skill" or "effort." The question therefore is: How is each of the 12 possible work contributions listed earlier affected by increasing levels of mechanization? Obviously, some of these contributions will decrease with increasing automation, but perhaps there are other demands that will increase.

---

[4] I believe that most of the erroneous thinking and claims regarding labor and "automation" have arisen because few people have critically examined the nature of mechanization. People not technically trained seem to assume that (a) machinery is either nonautomatic, highly automatic, or fully automatic (whatever that may mean); (b) an entire factory or production line has the same mechanization sophistication throughout its length; and (c) only mechanization explains progress in automatic manufacturing. All these notions are wrong. See *ibid.*, pp. 29, 39–56, for mechanization profiles plotting the degree of mechanization in each production operation throughout a number of "automated" factories.

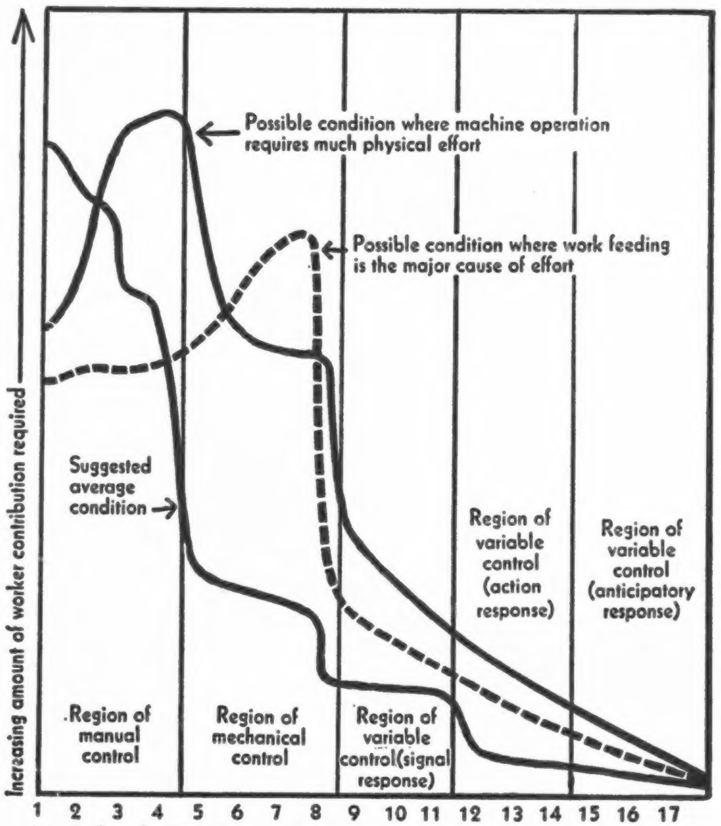
[5] And isn't this logical? If the machine is automatic—if it does more of the activity—doesn't the man attending it do less?

It does not seem possible to make accurate quantitative measurements of each type of "contribution," at least at this stage of our understanding, but it is worthwhile to examine several types of work contributions and hypothesize as to how they will be affected by increases in level of mechanization.

Physical Effort. If we were to chart the physical effort contributed by the worker against the level of mechanization, as shown in exhibit 4, it is clear that we would describe some kind of declining curve. That is, the physical effort exerted by the worker will be highest in the lower levels of mechanization, and it will decline abruptly once the fixed-cycle machines of level 5 are achieved. Notice that literally no physical effort is required after the completely automatic control of level 12 is reached, provided that work feeding and work removal have been mechanized.

Training and Education. But what about the need for knowledge? Is it not true that as a more complex tool is provided, the worker needs increased training in order to understand the operation of the machine, its adjustment, and its application to the task? After all, he must learn how the machine works, and he must know how to apply it to a variety of operations. For example, training a journeyman machinist takes up to 4 years.

EXHIBIT 4.—HOW PHYSICAL EFFORT REQUIRED OF OPERATORS MAY VARY WITH LEVELS OF MECHANIZATION



Courtesy of the *Harvard Business Review*.

When power is applied to the tool, and as adjusting and regulatory devices requiring careful adjustment to obtain proper application are provided, the worker obviously has to learn more about the machinery—perhaps much more if the equipment is complex. He also may need more training to understand the principles underlying the machine's operation and adjustment. Accordingly, the need for education and training definitely increases.

But does it continue to increase as automation approaches the higher levels? Apparently not. In the metalworking field and in many other equipments, the effect of automatic cycling (level 6) is to substitute workers of lesser training ("machine operators" for machinists).[6] The reason is almost self-evident: When a pattern of predetermined actions can be mechanically achieved, there is no particular need for the understanding, training, and education on the part of the operator that existed when adjustment and control lay in his hands.

Therefore, at some point after level 4, the education required by the worker no longer increases. After the mechanization levels introducing measurement (in effect, states in which the machine signals the need for human judgment), the critical judgment required of the operator actually becomes less. Again, the degree and point of change will vary with equipment, but the common effect seems to be a rising-then-falling curve, as hypothesized in exhibit 5. In many instances, the need for education and understanding of principles may continue well into higher levels. However, these eventually become unnecessary contributions as reliability increases.

Mental Effort. One of the major conclusions in the case study presented by Charles R. Walker in *Toward the Automatic Factory*[7] is a claim that mental effort is substantially increased by automation. A number of statements in union literature and speeches also insist that the mental strain on the worker is the most formidable demand imposed by automatic machinery. What does happen when we relate mental effort to levels of mechanization?

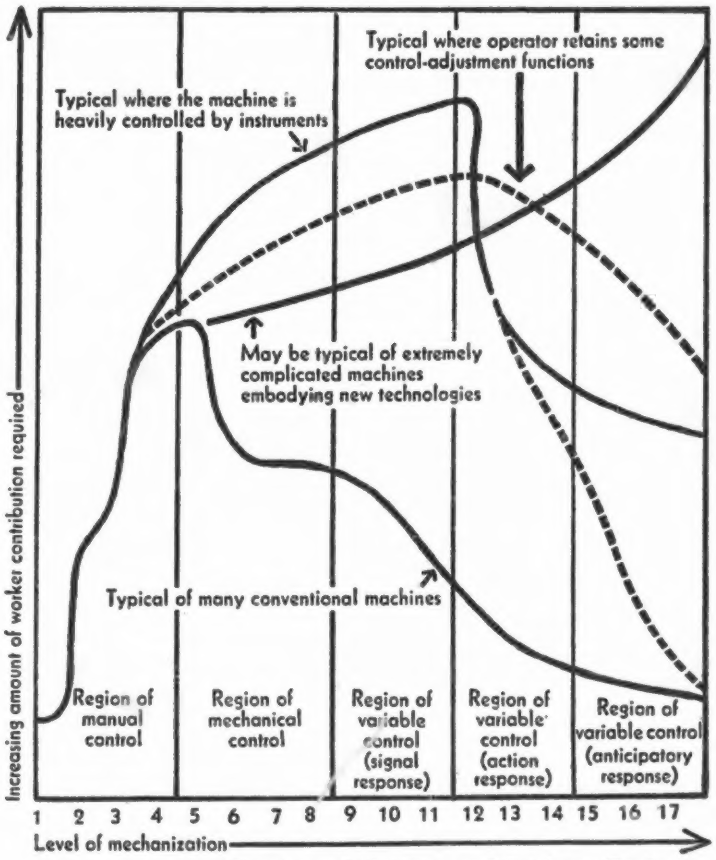
Obviously, when he works with hand tools (levels 2 and 3) and with hand-controlled equipment

---

[6] As an outstanding example, see "Automation and Technological Change," *Hearings*, Subcommittee on Economic Stabilization of the Joint Committee on the Economic Report, Congress of the United States, October 1955, p. 254.

[7] Charles R. Walker, *Toward the Automatic Factory*, Yale University Press, 1957; see also Charles R. Walker, "Life in the Automatic Factory," *Harvard Business Review*. January-February 1958, p. 111.

Exhibit 5.—How Education Required of Operators May Vary With Levels of Mechanization



Courtesy of the *Harvard Business Review*.

(level 4), the worker must concentrate in order to avoid misdirecting the tool, to "control" the activity, and to detect conditions that might disrupt successful functioning. As the machine provides the desired sequence of events (levels 5 and 6), the need for concentration on the actual direction of the machinery is reduced. At the same time, however, it is entirely possible that alertness to malfunctioning, to the quality of the output, and so on, is a far more worrisome mental task, at least in some instances, because of faster cycling. So on these levels increased mental strain might be a very real thing.

Consider next what happens as the machine is given the facility for measurement on levels 9–11. In a primitive way, the machine begins to detect and to report the character of some operating conditions. Therefore, the operator no longer needs to be quite as alert (depending on just what elements of the activity are measured and signaled). In some instances, as with safety valves, for example, the operator may be quite at ease until he gets the warning signal. A number of workers on highly automatic machining lines, in which automatic gaging and signaling of performance were employed, acknowledged this effect of automation. These men and women stated in many ways that they found the jobs less demanding because they were able to relax more than under former conditions. Attention, concentration, and mental effort were required only at the moment faulty performance was signaled.

The mental effort requirements would seem to be reduced further as still higher levels of mechanization are employed. Here the machine not only detects the need for a modification in its performance, but it begins to make such a modification without human attention. We might say that on levels 9–11 the machine calls for human help. On levels 12–17 the machinery adjusts itself, as necessary, in an increasingly sophisticated manner. By definition, more automatic machines employ control devices that regulate their performance to achieve the desired end without human attention. It must follow that mental strain is ultimately reduced.

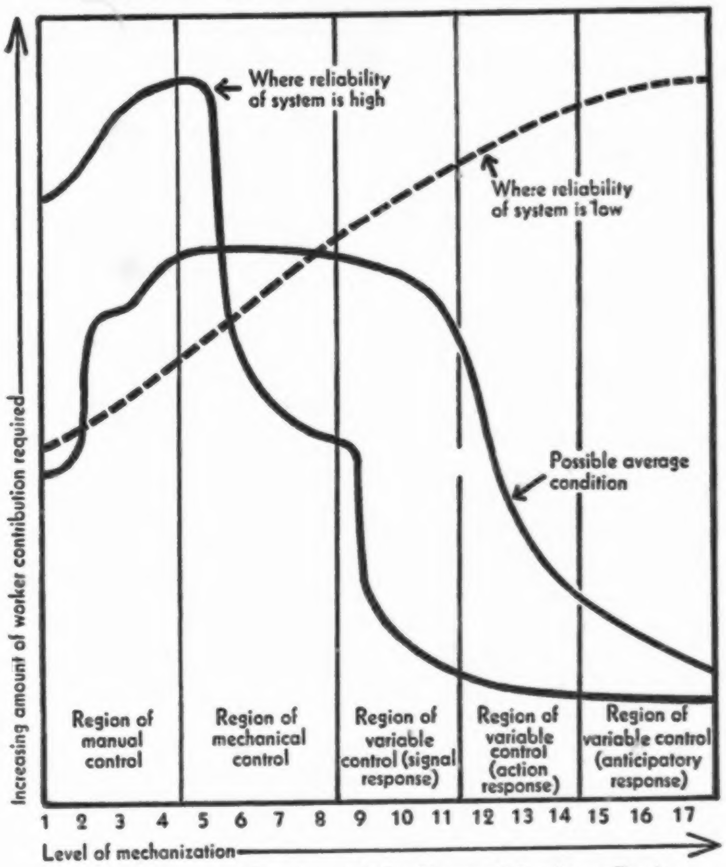
How, then, can it be said that mental strain will continue to grow with increasingly automation? Take Charles Walker's findings. On closer examination they are not contradictory at all. For, as Walker's description indicates, the steelmill he studied was not a level 17, or even a level 12 operation. The span of mechanization was broken at several points, much of the machinery operated at levels 5 and 6, and only in a few instances throughout the manufacturing sequence was level 12 reached or exceeded. Increased mental strain had resulted—not because the equipment was more automatic, but because it was not automatic enough. It was more integrated, faster, and bigger; but many "control" problems, now more critical than ever because of the potential for more serious error through increased speed and power, were still left to the workers. Even so, after the men once learned to live with the equipment, there was (I infer from their reported reactions) considerably less mental strain.

In sum, it is reasonable that a curve such as is shown in exhibit 6 may be a typical relationship of mental effort to increasing automation.

Other Contributions. Similarly, responsibility can be thought of as increasing with more costly and more highly integrated machinery. However, it increases only to the extent that the worker truly has responsibility, and the ultimate effect of the higher levels of automation is to remove responsibility for performance from the hands of the worker. The detection of faulty operation, overloads, malfunction, shortages, changing material, power requirements, and so on gradually becomes vested in the machine. At some point after level 11 or 12 is achieved, the control mechanism has the responsibility, not the operator.

Much the same can be said about "manipulative" skill. Up to about level 5 the need for physical dexterity may increase, but above that point the machine takes over more and more. The need for "general" skill increases up to about level 11, but

EXHIBIT 6.—HOW MENTAL EFFORT REQUIRED OF OPERATORS MAY VARY WITH LEVELS OF MECHANIZATION



Courtesy of the *Harvard Business Review.*

then the machine again begins to take over and the need decreases.[8]

One could construct similar relationships between the demands on the worker with respect to the other contributions listed earlier. While no curve could be drawn that would be universally applicable to all types of machinery, I believe that almost all such curves for individual cases would exhibit the same general characteristics; that is, at some higher levels of mechanization most worker contributions would decline. Thus, exhibit 7 suggests the changing character of demands on the worker with increasing levels of mechanization.

Combined Effect on the Worker

Production jobs never require just one kind of contribution by the worker. They involve combinations of several contributions in different degrees. Thus it is necessary to consider some kind of combined "demand on the worker" effect. This has been done in exhibit 8, which shows several curves suggesting the net effect on the contribution of the worker as the degree of automation increases. While it does not seem possible to prove quantitatively that these curves are correct, they were substantiated in concept by my observations of actual automated job requirements in industry.[9]

Counteracting Trends Raising Worker Contribution

It would be a mistake, of course, to assume that the reduction of job content is the only effect of automation. Three other happenings may counteract the effect of mechanization on the original task. These are developments that change the scope of the operator's duties:

1. *Responsibility for a larger span of the line.* Because less attention is required on a given machine, the operator may be given more machines to tend. He becomes responsible for the manning of a physically larger portion of the production sequence or a larger number of identical activities. This may require a knowledge of additional machines, and hence additional technical skills on the part of the worker; it may also require more effort and attention. The net result may be a significant increase in responsibility because of the possibility and/or probability of more costly damage if the system under his control malfunctions.

Therefore, as the worker becomes responsible for more machines, two types of effect are possible:

(a) He may be required to learn an additional technical art roughly on the same skill level as that which he previously possessed. For example, a milling-machine operator might be required to master a broaching machine and a drilling-tapping machine if they are integrated by automation in his work station. While these skills might not be more difficult or higher in degree, they definitely are additional requirements. They may or may not call for additional training.

(b) He may be required to learn an operation which involves a much higher degree of skill. I did not encounter many instances of this in my study. One example was that of a master control board operator in a fertilizer plant: Semiautomatic control of the mixing activity definitely demanded more understanding, attention, and responsibility from the operator.

2. *Responsibility for higher caliber duties.* In some automated jobs, the demands on the operator for conventional duties are practically eliminated, but his new duties may embrace a portion of the setup work or the inspection job. In other automated lines, there may be no operator in the conventional sense. The individual responsible for this area of the production line may be a setup man, a maintenance man, or an inspector.

To illustrate, I encountered an instance where a maintenance man was "manning" an automatic

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[8] Much of the confusion over the effect of automation on skills really stems from a definition problem, particularly the failure to distinguish between the operator's job and jobs of repairmen, quality control specialists, and others in the indirect labor force.

[9] Bright, *Automation and Management*, *op. cit.*; see examples throughout ch. 12.

EXHIBIT 7.—CHANGING CONTRIBUTION REQUIRED OF OPERATORS WITH ADVANCES IN LEVELS OF MECHANIZATION

WORKER CONTRIBUTION[1] OR SACRIFICE TRADITIONALLY RECEIVING COMPENSATION	MECHANIZATION LEVELS			
	1–4	5–8	9–11	12–17
	HAND CONTROL	MECHANICAL CONTROL	VARIABLE CONTROL, SIGNAL RESPONSE	VARIABLE CONTROL, ACTION RESPONSE
PHYSICAL EFFORT	INCREASING-DECREASING	DECREASING	DECREASING-NIL	NIL
MENTAL EFFORT	INCREASING	INCREASING-DECREASING	INCREASING OR DECREASING	DECREASING-NIL
MANIPULATIVE SKILL (DEXTERITY)	INCREASING	DECREASING	DECREASING-NIL	NIL
GENERAL SKILL	INCREASING	INCREASING	INCREASING-DECREASING	DECREASING-NIL
EDUCATION	INCREASING	INCREASING	INCREASING OR DECREASING	INCREASING OR DECREASING
EXPERIENCE	INCREASING	INCREASING-DECREASING	INCREASING-DECREASING	DECREASING-NIL
EXPOSURE TO HAZARDS	INCREASING	DECREASING	DECREASING	NIL
ACCEPTANCE OF UNDESIRABLE JOB CONDITIONS	INCREASING	DECREASING	DECREASING-NIL	DECREASING-NIL
RESPONSIBILITY[2]	INCREASING	INCREASING	INCREASING-DECREASING	INCREASING, DECREASING, OR NIL
DECISION MAKING	INCREASING	INCREASING-DECREASING	DECREASING	DECREASING-NIL
INFLUENCE ON PRODUCTIVITY[3]	INCREASING	INCREASING-DECREASING OR NIL	DECREASING-NIL	NIL
SENIORITY	NOT AFFECTED	NOT AFFECTED	NOT AFFECTED	NOT AFFECTED

Courtesy of the *Harvard Business Review*.

[1] Refers to operators and not to setup men, maintenance men, engineers, or supervisors.

[2] Safety of equipment, of the product, of other people.

[3] Refers to opportunity for the worker to increase output through extra effort, skill, or judgment.

line. On another line where pistons were milled to weight automatically, the "operator" combined the remaining conventional operator duties with those of a setup man. He put the system into operation, verified performance, and made adjustments. He had to have a knowledge of machinery distinctly above that of a machine operator (although not necessarily above that of a journeyman machinist or a versatile job setter). Clearly, an upgrading of the job has resulted.

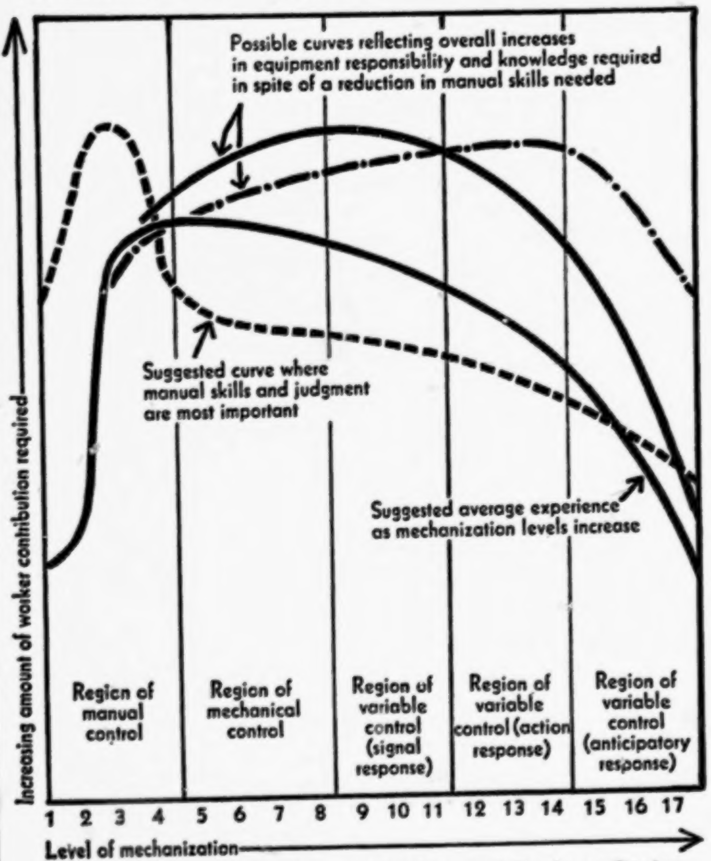
The line between "set up" and "operate" is a narrow one. In many industries an individual may perform the same setup function described above without distinctly superior knowledge and training. Operators on some kinds of textile machinery are a good example. Therefore, this source of job content increase is not necessarily serious, but it could be significant in other instances.

3. *Addition of new "specialists" jobs.* One upgrading effect of automation is to create new kinds of skilled jobs. These may require distinctly superior education or demand significantly higher levels of comprehension and responsibility. Operators of master control panels may exemplify this trend.

Realistic Evaluation. Each of these happenings works in some way against the declining curves shown in exhibit 8. We should not, however, jump to the conclusion that automation will always substantially upgrade the work force. The fact is that the job changes just described do not exist in any great number in industry—even in plants with a high overall level of mechanization. Take the third category, for instance—specialized jobs in the remote control of operations. Often a highly mechanized factory will have only one control board job of the type described, and, at the most, only a handful of such positions. Accordingly, the net effect of automation in almost every plant I studied was still to reduce—or at least not to increase—the demand for skills and abilities of the direct labor force.

As in the factory, so in our everyday life. Is today's car with automatic choke, automatic transmission, power brakes, and power steering harder or easier to drive than a Model T Ford? Who needs the greater skill and experience for successful performance: The housewife who bakes in an

EXHIBIT 8.—HOW TOTAL CONTRIBUTION REQUIRED OF OPERATORS MAY VARY WITH LEVELS OF MECHANIZATION



Courtesy of the *Harvard Business Review.*

automatic oven, or her grandmother who had to learn the art of baking in a coal stove through lengthy experience and who had to apply continuous, critical attention for successful results?

Indirect Labor

What about the effects on skills of shifting direct labor personnel to indirect labor jobs?

As automation displaces the machine operator, the line between direct and indirect labor becomes hard to distinguish. Has the operator become a setup man or the setup man an operator? Regardless of the answer, an important skill change is evident in the setup activity. Machine preparation and adjustment frequently are more complex and more difficult, and require a wider range of technical knowledge and competence. This is due not only to the complexity of the equipment, but even more to the intermingling of the five types of control systems—hydraulic, pneumatic, electrical, electronic, and mechanical. Also, work-feeding devices must be synchronized and otherwise regulated, and new degrees of precision must be obtained by careful adjustment.

The increased demands imposed on the setup man are quite noticeable when a plant moves, say, from level 4 of mechanization to level 12 or higher. On the other hand, if the old equipment already required a high degree of setup skill (as on a conventional engine-block line), then the move to automation probably does not increase the setup man's skill and training requirements significantly. In the case of one of the first automated engine plants, for example, all job setters and their supervisors were given 3 hours of training in addition to the basic familiarization course given to the operators. Does this mean that there has been a distinct increase in the demand on job setters' knowledge?

Where indirect labor mans non-production-line machinery, such as powerplants and material-handling devices which are in themselves automated, the result is comparable to that for production-line machinery. The demand on the worker increases up to some point; then the increasing automation of the machinery generally begins to reduce his contribution in almost every respect.

To be sure, some new kinds of indirect-labor jobs requiring a high degree of technical education may be created. An outstanding example was the introduction of numerically controlled machine tools. The programing of tapes initially required considerable technical education. (These duties might be regarded as setup jobs of a very high caliber.) Engineering or mathematical training was the bare minimum education for developing programing instructions. Today the situation is quite different because of automation progress, as will be discussed shortly.

Plants that build their own automatic machinery have a greater requirement for the peculiar talents needed for machinery development, and they are the main source of complaints about the shortage of adequately skilled people. Not only is technical training needed, but also some kind of skill in visualization, imagination, and mechanical creativity. The last was by no means obtainable simply by hiring more engineers, according to several experienced managers. The real production bottleneck was in this area of conceiving, designing, and building new machinery, a peculiar aptitude not necessarily related to formal education. Significantly, firms that did not build their own equipment—and they were in the clear majority—had no complaints of this sort.

Maintenance Force Effects

As mentioned earlier, it is popularly assumed that maintenance will increase absolutely, or at least proportionally, under automation. Is it not therefore obvious that the maintenance force will require a new order of skill?

This cannot be answered with a simple "yes" or "no" because the maintenance force comprises a number of kinds of skill, and these are not all equally affected by moves toward automation. For instance, I found no evidence that tinsmiths, pipefitters, welders, and carpenters required increased skill, some evidence that hydraulic and pneumatic repairmen need better training because of the increased complexity of the control circuitry, and much evidence that a significant proportion of electricians need extensive additional training.

The average plant electrician is no more prepared to cope with electronic circuitry than the average household electrician is able to repair a TV set. It is a whole new technical world, and it most definitely requires specialized training in theory and practice. One major engine plant has studied this problem and concluded that almost 2,000 hours would be needed in class and shop work to provide adequate electronic training in addition to the firm's existing journeyman electrical training program of 3 years.

All plants studied that employed even small amounts of electronically controlled machinery offered the same complaint about maintenance skills. Frequently, the shortage was so critical that it distorted attitudes toward the entire maintenance problem. For instance:

> Lack of electronic maintenance skills was stated to be a critical problem in one plant, and indeed it was. On closer examination, however, it was found that not every electrician needed electronic training. Of 700 men on maintenance, approximately 80 were electricians, and the plant engineer estimated that he needed just 3 to 4 competent electronic repairmen per shift. In other words, only about 10 percent of his electricians needed the specialized skill—and these amounted to only 1 percent of his total maintenance force.

Such percentages do not make the shortage less critical, but they indicate quite a different scale of difficulty and a much smaller retraining problem. They also suggest that we avoid loose statements which distort the problem and national actions that are out of proportion with the real need.

Automation also suggests the need for a new type of repairman, competent in the five kinds of control circuitry involved, since it is too costly to send out a whole crew of repairmen or a succession of individual specialists, each going to the limit of his technical field then requiring another to take over. The downtime implications are more than disturbing as the span of mechanization grows. Obtaining the necessary maintenance ability involves a training problem and a union relations problem which relatively few managers have tackled. It deserves concerted attention.

Quantitative Effect of Automation on Individual Factories. Automation resulted in an increase in both the size and the percentage of the work force devoted to maintenance in several instances studied and a substantial decrease in several others. Thus:

> A plating plant quadrupled its maintenance force while increasing output 50 percent with the same total employment. Maintenance is now about 15 percent of the total work force.
>
> In a major metalworking plant the maintenance force increased from 700 to 900, while direct labor was reduced. The new work force, therefore, was made up of about 30 percent maintenance personnel, as compared to an estimated 10 percent in a roughly equilvalent prewar operation.
>
> A bakery doubled its maintenance staff while reducing its total work force about 35 percent. Maintenance now became about 8 percent of the total work force.

On the other hand, the following firms found that automation did not require a larger maintenance force:

> The most automatic small refinery in the U.S. in 1954 had a maintenance force amounting to 21 percent of the total work force. Conventional refineries show a 50 to 60 percent ratio.
>
> Two major parts-manufacturing plants, each employing over 10,000, have devoted their attention to automatic production since 1946. Both are well known in engineering circles for outstanding automation accomplishments and use literally hundreds of highly automatic machines. Both maintenance forces are characterized by one peculiarity—lack of change. The maintenance force has remained a steady 3.5 to 5 percent of the work force in one firm, and 6 to 8 percent in the other, over the last dozen years of aggressive mechanization with automatic machinery.
>
> In 1953 a small farmer's cooperative built the most automatic feedmill in the U.S. and reduced its work force from eight to three. What happened to maintenance? "We fired the maintenance man. We just don't need him any more." The automatic plant was new; the nonautomatic plant was old, and hence subject to more breakdowns.

These and other experiences indicate that the effect of automation on the maintenance force has been misunderstood. One of the reasons is a failure to appreciate the true nature of the maintenance "problem." A firm feels maintenance effects as a "before automation" versus an "after automation" contrast. It is the degree of this change that helps to create the "problem," not the absolute degree of automation employed. This maintenance contrast is proportional to a mix of maintenance-increasing and maintenance-decreasing factors.[10] For instance:

> One of the effects of automation is to compress the production line and literally to reduce the total physical amount of machinery for a given output, even though that machinery may be more complex. Hence in several instances the maintenance force was reduced simply because the total volume of machinery was reduced. This reduction more than compensated for the increase in the complexity of the equipment.

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[10] For charts of maintenance-increasing and maintenance-decreasing factors, see Bright, *Automation and Management, op. cit.*, p. 165.

Also, maintenance is not proportional to the automation of the machinery, as we instinctively tend to assume, but is more nearly a reflection of the novelty or uniqueness of the equipment. While highly automatic machinery may give very little trouble when perfected, the maintenance of the first unique machine may be extremely costly and frustrating because much "debugging" and lost production time occur while design refinements are being made and maintenance experience is being gained.

Engineers and Technicians. Those firms that do not build their own automatic machinery obviously will not hire designers and builders, but will they need more technical support for operations? In a few instances, I found upgrading of foremen had taken place. Here and there engineering graduates were being hired as line and maintenance supervisors. While the number of such instances was small, the lack of adequately trained supervisors was one of management's principal complaints. The missing ingredients, it was claimed, were alertness, perception, and judgment with respect to equipment operation and the implications of downtime. "The ability to see ahead—to plan instead of to live from hour to hour—is what the old line foreman doesn't have."

In spite of this feeling, it was significant that almost all of the firms studied were getting along with their old foremen.

However, in the 9 years since these conclusions were first reached in 1957, I have noted a definite trend toward hiring college-trained men for supervisory jobs. However, rather than a greater technical education, it seems these jobs demand an understanding of the need for change and an ability and willingness to see and accept new relationships. Nevertheless, I feel sure that many highly automatic systems, such as automated warehouses, will require college-trained supervisors. The foreman's job is being upgraded more severely than the worker's job, for it is the foreman who must grasp and respond to a different set of needs, since he is the "operator" of the master machine—the highly automatic production line.

How Theory and Experience Confirm Each Other

In total, then, these limited observations and the theory offered here suggest that automation does not necessarily result in an increase in skill requirements. In fact, automation often tends to reduce the skill and training required. How can this be explained in view of examples to the contrary? It is significant that our general hypothesis accounts for these diverse observations very well.

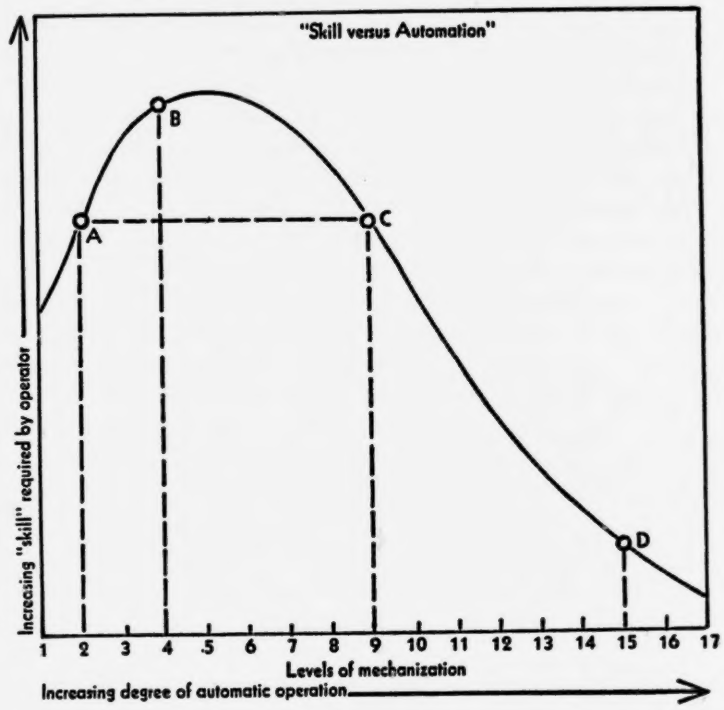
Notice the characteristics of exhibits 4 through 7, and particularly exhibit 8, which combines all worker contributions. The curve of skill requirement (worker contribution) rises with lower levels of mechanization, and then falls off at higher levels. In general, there is a "hump" in skill requirements as machinery evolves toward automatic operation. Then this experience is possible:

Consider a given job, mechanized on level 2 with skill requirement as indicated by point A on exhibit 9. If the task is mechanized to level 4, skill requirement will be raised to point B. If mechanized to level 9, skill requirement will be at point C, approximately the same as the original job. Mechanizing to level 15 puts skill at point D, a far lower skill requirement than the original task. Thus the effect of increasing the degree of automation (raising the level of mechanization) could raise, lower, or leave unaltered the demand on the worker. The change in skill required depends upon the level of mechanization of the original job and the level to which it is raised. This explains why clerical workers shifted from conventional jobs (levels 1, 2, 3, and 4) to work on computers (level 15) may report that the work is less demanding (and less satisfying).[11] They have leaped across the hump in skill requirements, and therefore worker contribution is declining.

Effects of Continuing Automation Progress

These general conclusions were arrived at in 1956 and published in 1958; they have been tested in the

EXHIBIT 9.—WHY ADVANCES IN AUTOMATION CAN HAVE CONTRARY EFFECTS ON SKILL REQUIREMENTS



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[11] See I. Hoos, "When the Computer Takes Over the Office," *Harvard Business Review*, July–August 1960; also many recent studies by the U.S. Department of Labor.

years since against industrial situations. It is useful to see what has happened to the types of tasks that seemed in 1958 to require higher skills. Consider:

The setup man. Several machine tool firms have announced highly automatic machines in which setup is performed by the push of a button. The Milwaukee multimatic machine tool is an example. Thus the setup task is being mechanized to an important degree. Skill requirements in such instances are dropping.

The availability of computer languages and of standard programs that can be adopted by many users are other examples of reducing the skill required by the setup man. In other words, the complex, automatic machine—the computer—has been so developed by its builders that the setup skill needed by the user is significantly lessened.

The numerical control tape programer. As mentioned earlier, the numeric control machine tool raised the new and difficult task of programing the tapes. Today, programing has been so simplified that draftsmen can program the tapes through special "languages" adapted to the computer. The educational and special training requirement has dropped severely.

The maintenance man. It is clear that mechanization and simplification of the maintenance task itself is occurring simultaneously with more automation. Mechanization of maintenance examples include automatic lubrication, automatic signaling of performance, and mechanized identification of the area or cause of failure. Indeed, the computer itself is being used to check out automatically the most complex circuitry in aerospace vehicles, defense systems, power systems, etc. Troubleshooting routines and special testing circuits are facilitating the detection and repair of faulty parts.

Automation literature has been singularly neglectful of the machine designer's efforts to simplify maintenance. By using more rugged components, by redesigning for durability, by stress on reliability as a design goal, automatic equipment is steadily being improved. Other design concepts have simplified the act of repair: Modular replacement of malfunctioning sections of machines, color coding of different circuits and systems, quick removal connectors for pipes, wires, and mechanical parts, plus design for accessibility will help to reduce the maintenance problem.

This is not to deny that the growing complexity of many devices is increasing the maintenance required. But we should recognize that the machine designer's efforts also are offsetting and reducing some maintenance needs. The game is not totally one sided. We have eloquent testimony to this in our homes, where transistorized electronic equipment has reduced the frequent maintenance formerly required because of failure of vacuum tubes. Refrigerators run a lifetime with virtually no repair, and millions of automatic automobile transmissions never give trouble.

Maintenance is, however, the most serious "skill" problem in automation. The effect varies with different crafts and seems sharpest in such fields as electronics, hydraulics, pneumatics, instrumentation, and machine repair. Many unions and firms are responding to the need by special training courses and special texts. In *Chemical Engineering* of October 12, 1964, Thomas Dugan, business manager for Local No. 420, United Association of Journeymen and Apprentices of the Plumbing and Pipefitting Industry, describes his union's experience over the last 9 years and concludes:

> We have thus been able to supply with rare exceptions all of the highly skilled personnel necessary for today's installations. With our ever improving intra-union educational system, I see no reason why we should not be able to supply a sufficient number of highly trained mechanics to work on the increasingly complex plants of the future, and at the same time meet the needs of our members for staying abreast of the technology.

Although the net effect of automation on reducing total demand for maintenance skill is minor, the theory proposed here is not invalidated. Indeed the relationship of highly automatic machinery and skill requirement is confirmed as a concept, even in the maintenance field. Computerized checkout of complex systems has definitely speeded and simplified the maintenance task.

Thus, though the maintenance content of our total work force is probably rising, it is not correct to assume that this is due solely to automatic production machinery. It undoubtedly also is a reflection of (1) the growing amount of machinery, and (2) the elimination of operating jobs and unskilled indirect labor jobs, which changes the proportions of maintenance jobs to operating labor in the work force.

The work force supporting the computer. Numerous reports confirm that routine operation of the computer and even programing do not require the high order of skill and training anticipated in the mid-1950's.[12] It is startling to find that some schools are training sixth graders to work with the computer, that high school dropouts have been trained as computer programers (by the Department of Labor in 1965), and that convicts are being trained as computer programers. The lesson should be increasingly clear—it is not necessarily true that highly complex equipment requires highly skilled operators. The "skill" can be built into the machine.

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[12] *Ibid.*

The Effect of New Products On Skill

The manufacture of certain new products suggests that a new trend will spread into parts of industry and will affect the caliber of skill required by the worker. This trend is evident in at least three industries—computers, defense, and aerospace. In most industries the trend has been toward mass production of products simplified for manufacturing (although often more complex because of added features) in even larger numbers. Yet here we have growing industries characterized by:

1. Extremely complex products.
2. Continuous technological change involving much research and development.
3. The number of units of any one model produced is very small, frequently only one.
4. The cost of each unit is very high, frequently in the tens of millions of dollars.
5. Highly precise manufacturing, assembly, and testing are required.

This kind of manufacturing requires a work force with a high proportion of technically trained people ranging from applied scientists through test engineers and master machinists. Thus the skill of the total work force requires drastic upgrading. Note, however, that this results because the amount of automation in manufacturing is less, and not because its effects are different from those suggested here.

There is no doubt that greater numbers and higher special skills are needed to design and build the complex products of defense, aerospace, and many industrial processes.[13]

Growth in the proportion of higher skills in supplier firms and industry work force will continue, but we should be very careful not to confuse the causes of the need for skill. The need arises mostly on the design side of the firm's activity, and in that manufacturing work not susceptible to mechanization. It is the hand assembly and hand testing of complex, one-of-a-kind devices that requires engineers on the production floor. Given enough volume, these tasks are mechanized and otherwise routinized so that conventional labor forces can carry out the work.

Similarly, there is a rise in the skill (in this instance, largely, but not solely, education) required by many other professionals, for example, doctors, lawyers, teachers, managers, military officers, and administrators of institutions such as libraries, natural resource systems, and many government agencies. This is due to the growth of knowledge and the refinement and addition of techniques.

It is significant that automation—of both physical and intellectual requirements—offers the greatest hope of reducing the skill required. Thus, the hospital turns to automatic machinery for analyzing samples so that unskilled help can provide rapid and accurate analyses; the librarian and lawyer are seeking to simplify their work through using the computer as a search-and-recall tool; and in thousands of ways the computer is being used to improve the results and to simplify the human contribution in industry; for example, in purchasing, electric motor design, choosing warehouse locations, and selecting optimum shipping methods.

The National Skill Problem

As a Nation we must consider the total impact of all technological and economic change on the skills needed by our society. The theory proposed here deals only with the effect of increasing automation on the operators needed to man the more highly automatic machines. The national picture on skill remains very confused because of the demands of new, major efforts in the defense and space industries, as well as automation and other technical phenomena. The confusion of counteracting trends is nowhere better summarized than by one of the world's leading students and practitioners in the employment statistics field, Ewan Clague, Commissioner of Labor Statistics, U.S. Department of Labor. In a superb review of the effects of technological change on occupational patterns in the U.S., he identifies the skill-increasing trends in occupations such as maintenance, and

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[13] "Manpower for Research and Development," Study No. II, Report of the Select Commission on Government Research, House of Representatives, 88th Cong., Washington, D.C., September 1964.

This careful examination shows many important data about the growth and use of scientists and engineers in the work force. It is hard to discern an "automation machinery design" component through the statistics they cite.

One highlight is: From 1957 to 1963, the number of research and development scientists and engineers in industry increased from 224,000 to 339,400. In the "machinery" category, numbers increased from 24,200 to 32,300. "Electrical equipment" other than communications increased from 23,700 to 34,500. "Aircraft and missiles" increased from 61,100 to 105,200. In other words, the industries building machinery and electrical equipment (which includes controls), added about 20,000 research and development men. Meanwhile aerospace added about 44,000 research and development people.

But we must admit that automation activity (i.e., automatic machinery) cannot be identified by these statistics. In 1960 all scientists and engineers were distributed by employment as follows:

Research	135, 000
Development	290, 000
Production operations	395, 000
Administrative and management	125, 000
Teaching	80, 000
Other	250, 000
Total (approximately)	1, 275, 000

Of this total, 865,000 were employed by industry.

points to offsetting and unappreciated trends, such as:[14]

> (1) Occupational skill levels reduced because of proliferation of subspecialities (and, I would add, their partial mechanization); e.g., shoemaking has been diffused into over 50 occupational tasks (cutter, stitcher, etc.), requiring little skill.
>
> (2) Tape control (of machine tools and typesetting machines), which "operate" the machines to a precision and consistency hardly attainable by human beings, yet capable of being manned by operators of lesser skill than formerly. (This machinery falls on level 6, and at times, level 12 and up of exhibit 3).
>
> (3) Preassembled components in carpentry and other construction work, which reduces craft skills. (This is also most apparent in the housewife's tasks of food preparation, in toys, and in hobbies.)[15]
>
> (4) Employment in over 80 occupations, many of them skilled (loom fixers, cabinetmakers, furriers, stonecutters, locomotive engineers), has declined since 1950.

After considerable statistical comment on both sides of the question, Mr. Clague says:

> My own judgment is that on balance, the trend of skills is upward, but I do not have the analytical data with which to answer this question with certainty.[16]

If a national trend is not crystal clear to a man with this experience and statistical resources, it certainly suggests that we should regard the "automation raises skill" theme with great caution. His macrostatistics on a national level, let it be noted, do not deny the possible validity of the theory proposed in this paper.

Mr. Clague concludes with a recognition of the need for more education in society in order to better equip workers to shift to new jobs, perceive new needs and opportunities, and achieve greater adaptability and readiness to learn. Also, employers may demand higher education as a condition for employment. He cites a supermarket chain as hiring only high school graduates to stock shelves.

I have observed two other phenomena that distort the true effects of automation on required work force skills:

(1) *The "insurance" philosophy:* Many executives realize that the more automatic plants do not require higher skills when running as planned. But if failure occurs, they feel traditional skills will be required to operate the plant manually. We cannot quarrel with this approach, where it is valid. However, I have found that the numbers of such higher skilled persons are sometimes excessive. Furthermore, as years go by and equipment reliability is improved, the original assumptions on the amount and type of insurance personnel needed are invalid and lead to substantial overstaffing;

(2) *The "startup-debugging" skill specification:* Many pioneering installations are, in fact, quasi-development projects (even though not intended as such). Highly skilled operators and maintenance men are needed during this troublesome period. The difficulties become so sharply etched in management's mind and in the industry's appreciation of the automation concept, that the skill requirements are assumed to be permanent. Experience and machine design refinement ultimately reduce this skill requirement, yet firms and industries may fail to adjust accordingly.

I suggest that excessive educational and skill specification is a serious mistake and potential hazard to our economic and social system. We will hurt individuals, raise labor costs improperly, create disillusion and resentment, and destroy valid job standards by setting standards that are not truly needed for a given task (except when future technical advances or general citizenship standards require that higher education).

This is not yet a major problem in my opinion, but it is an evident phenomenon and a tendency we should watch.

The Law of Automation Evolution

Once an economic-technical activity (which may require very high skill) has been analyzed, it is susceptible to mechanization. If the economic-social importance is high, both mental and physical activities in the task will be reduced or improved in performance by mechanizing elements of the work. Gradually all elements are mechanized and physically integrated, and then the system is "automatic." During this evolution the high skill needed to (a) manually execute the task, and (b) build, install, and debug the automatic system of doing the job, gradually declines. The skill and the amount of labor required to carry on the activity reduces to the level that is readily available in the work force and of no significantly higher cost than for the less mechanized system.

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[14] Ewan Clague, "Effects of Technological Change on Occupational Employment Patterns in the United States," Conference on Manpower Implications of Automation, Organization for Economic Cooperation and Development, Washington, D.C., Dec. 1964.

[15] While we may be glad to see industrial preparation reduce skill requirements in cooking, clothes, and household maintenance, there is a negative effect in other areas. As one example, the model airplane manufacturers and their hobby magazine publishers have just about destroyed the sport for youngsters. In their preoccupation with selling more expensive, complex items, they have neglected the beginner. By giving him only prefabricated kits, they have destroyed the creativity and fun in building one's own design. There is no creativity left on the beginner's level, and hence few youngsters show much interest in the sport relative to 25 years ago.

While model airplanes are a trifling element in our economic activity, they exemplify the social-economic trend of "prefabrication" that is rapidly eroding the mechanic-handicraft skill which was traditional in the American scene.

[16] Clague, *op. cit.*, p. 20.

This leads us to state the unappreciated "law of automation evolution":

> Machinery gradually evolves to provide that degree of automatic operation justified by economics, and having a simplicity of operation and maintenance that is economically supportable by the level of skill that can be made readily available in the existing work force.

While there are temporary imbalances, higher costs, and excessive skill demands on the operating and maintaining work force as this evolution proceeds, the machine designer ceases his efforts to simplify operation and maintenance only when the machine manning needs have been reduced to a standard that is normally available in the local work force. The economic incentive for automation progress disappears at this point.

Conclusion

The increase in skill required in our society may be very real and very significant, but because of this technical-economic law it stems only in minor part from the use of automatic machines. The great work force skill dislocations and imbalances in our society are due also to at least six other major technological developments.[17]

As a nation we must be careful to develop manpower policies that will be appropriate to the full sweep of technological progress, and that are not narrowly focused on one or two phenomena. Furthermore, this paper should highlight the need to examine actual effects on the work force with care rather than emotion; and from present facts rather than past personal experiences.

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[17] Automation of physical and intellectual work is only a fraction of technological progress affecting the work force. See J. R. Bright, *Research, Development and Technological Innovation* (Chicago, Richard D. Irwin, 1964), ch. 1. Here technological trends are identified and their effects on business, and hence employment, are pointed out. These trends of man's increasing technical capability are: (1) Transportation; (2) mastery of energy; (3) control of the physical environment and life forms; (4) ability to alter and synthesize materials; (5) extension of man's sensory capabilities; (6) mechanization of physical acitvities (automation); (7) mechanization of intellectual activities (automation); (8) control of human life.

Note that trend 4 has and will result in severe industrial and industry-natural resource struggles with serious employment impacts.

CHANGES IN THE SKILL REQUIREMENTS OF OCCUPATIONS IN SELECTED INDUSTRIES

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Changes in the Skill Requirements of Occupations in Selected Industries

Introduction

While "technological change" has been with us for a long time, "automation" is a relatively recent postwar phenonemon. No effort is made to distinguish sharply between them. The term "automation" seems to imply more drastic and more rapid changes, and, therefore, it is frequently used because of its startling and abrasive effects.

Regardless of the terminology, the phenomenon of technical change in industry has aroused the interest and concern of many persons throughout the United States and the rest of the world. Because of the acceleration of change during the past 20 years of the postwar period, the causes and effects of these technical changes have been the subject of thousands of books and articles. Empirical and speculative studies have been made on this subject by the members of many professions, including economists, sociologists, psychologists, industrial engineers, labor relations experts, and newspapermen.

1. Analysis of the Literature

Our primary interest is the effect of automation or technological change upon the skill requirement of occupations. With reference to any single industry, we are interested in knowing which occupations, if any, have been eliminated, and which, if any, have been newly created. For both eliminated and new occupations, we are interested in work content, and in the education, training, and other personal requirements needed for successful performance. For other occupations, we are concerned with changes in content and worker skill requirements resulting from technological change.

Limiting our focus to the past 15 years, we examined various bibliographies and indexes in an effort to pull together the literature relevant to our field of interest. Over 500 bibliographic titles were selected for careful scrutiny and analysis. The overwhelming majority of these speculated about the effects of automation based upon general impressions, discussions with a few industrialists or union leaders, or a few very limited case studies conducted by others. If an article or book discussed automation and manpower, it typically referred to employment opportunities resulting from technological change, the effects on the occupational structure of the plant or industry, or the effects on the skill composition of the labor force. Only a small number of studies made any effort to investigate and analyze the effects of automation on job content and the worker characteristics required of the changing jobs.

The relatively few empirical studies of the effects of technological change have been the basis for numerous speculative articles. A number of these have done an able job in analyzing the case studies completed by others, and in speculating about the general effect of technological changes in certain industries or occupational groups.[1]

A number of studies have been completed on the changing occupational patterns in specific industries, that is, changes in the distribution of employees among the various occupations of an industry. Some of these studies have made significant contributions to an understanding of employment opportunities, but they have not reflected investigation of the effects of technological change on job content and skill requirements, our special points of interest.[2] For example, Drucker's analysis of automation has machines doing materials handling, machine setting, and data processing. He sees automation's most important impact not on employment but on qualifications and functions of employees; worker displacement will involve primarily a shift in job opportunities, where higher grade skills and more education will be needed.[3]

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[1] See, for example, John Diebold, "Automation—The New Technology," *Harvard Business Review*, November–December 1963, pp. 63–71; "The Erosion of Jobs and Skills," *American Federationist*, October 1963, pp. 6–12; and Edgar Weinberg, "An Inquiry Into the Effects of Automation," *Monthly Labor Review*, January 1965, pp. 7–14. In the last article, the author speculates that many unskilled jobs will be eliminated, semiskilled jobs will be upgraded to skilled ones, and skilled jobs will be upgraded to technicians. See also C. C. Killingsworth, "Automation in Manufacturing," *Industrial Relations Research Association Annual Proceedings*, 1958, Pub. 22, pp. 20–34, in which the author concludes from an extensive review of the literature that there are few cases in which factory automation as such raised the skill requirements of machine operators.

[2] See, for example, Joseph A. Beirne, "The Job Revolution in Telephone" (Washington, Communications Worker of America, Education Department, 1959); U.S. Bureau of Labor Statistics, *The Railroad Industry*, 1947–60, Bull. No. 1344; and U.S. Department of Labor, Bureau of Apprenticeship and Training, *Foundry Training Needs*, May 1956.

More work has been done in studying the technological change on office workers than any other single occupational group. Nevertheless, there is no general agreement as to the effects of automation on office jobs. The occupations involved cut across industry lines, and the research covers a wide variety of office occupations.[4] A number of the empirical studies of office work examined the effects of automation on job content. Einar Hardin, in his article "The Reactions of Employees to Office Automation,"[5] noted that the job content of various occupations was changed as the result of automation. He concluded that personnel in the "computer area" were given more tasks, for which they had to learn new forms, codes, and sorting and tabulation routines, and devise new procedures for correcting errors. Personnel in the "coding and policy typing areas" lost many tasks and were given practically no new ones; however, for the remaining tasks they had to learn new forms, codes, and procedures. Ida R. Hoos reported similar findings from a 2-year study of 19 business concerns and Government agencies that had introduced electronic data processing.[6] The author concluded that for every five office jobs eliminated, only one new job was created; and the jobs not eliminated were drastically changed. A highly skilled elite of programers and analysts was created, but the remaining routine jobs showed little upgrading of skills.

A BLS study, "Impact of Office Automation in the Internal Revenue Service," found that job skills had been increased in many office jobs; a number of unskilled jobs had been eliminated; and some newly created jobs were relatively highly skilled.[7] In contrast, 3 years earlier the *Monthly Labor Review* noted that while office automation meant the creation of new jobs, such as programers, operators, and managers of electronic data processing machines, skill requirements remained stable for such routine jobs as posting, filing, tabulating, and key punching.[8] Approximately 80 percent of the employees affected were in routine clerical jobs and continued to do the same type of work after automation was introduced. About 16 percent went to slightly different types of routine work, for example, from computing to posting and checking. In summarizing the findings of some empirical studies of office automation, Floyd C. Mann concludes that there were few if any basic changes in the content of office jobs.[9] C. E. Weber, in testing the hypothesis that electronic data processing raises skill requirements of clerical personnel, found that although highly skilled technical jobs were created by the installation of computers, clerical workers tended to be downgraded.[10] Other empirical studies show no uniformity in the conclusions reached as to the effects of automation upon skill levels.[11]

The Bureau of Labor Statistics has unquestionably done most of the empirical research in the United States on the effects of automation and technological change on job content and occupational structures. In its study of an oil refinery, it found the education standards for production and supervisory personnel had risen as the result of new technology.[12] High school and preemployment tests were required for production personnel, and engineering degrees for supervisory. For the employees operating new "cracking and cooking" equipment, extensive on-the-job training of 3 to 6 months was required. Futhermore, the new technology created such new jobs as operators, helpers, and stillmen for the new cracking and cooking machines. A few unskilled laboring jobs were eliminated.

In a series of studies, the Bureau of Labor Statistics investigated the impact and effects of technological change and automation on selected companies and industries. The emphasis of most of these studies was on the occupational structure. The first, dealing with the manufacture of electronic equipment, found that automation eliminated some unskilled job opportunities, created certain new machine operations employing somewhat higher paying labor, and opened some additional jobs in skilled occupations; but many hand labor jobs still remained.[13] The second study, on the adoption of electronic data process equipment in insurance[14] considered factors contributing to the success and ease of adjustment to the introduction of the computer.[15] In the third study, involving a large mechanized bakery,[16] the introduction of automatic technology was found to have resulted in a number of new job classifications at higher skill levels as well as a few operative jobs with definite increases in responsibility.

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[3] P. F. Druker, "The Promise of Automation, II, *Harpers's Magazine*, April 1955, pp. 41–47. See also William Glazier, "Automation and Joblessness," *Atlantic Monthly*, August 1962, pp. 43–47, in which the author concludes that skill requirements are reduced by automation and retraining will not overcome unemployment.

[4] See, for example, Ida Russakoff Hoos, "The Impact of Office Automation on Workers," *International Labor Review*, October 1960, pp. 363–388, and International Labor Organization, *Effects of Mechanization and Automation in Offices*, prepared by the ILO Advisory Committee on Salaried Employees and Professional Workers (Geneva, ILO, 1959).

[5] *Monthly Labor Review*, September 1960, pp. 925–932.

[6] Ida R. Hoos, "When the Computer Takes Over the Office," *Harvard Business Review*, July–August 1960, pp. 102–112.

[7] U.S. Department of Labor, Bureau of Labor Statistics, *Impact of Office Automation in the Internal Revenue Service*, Bull. 1634 (Washington: USGPO, April 1963).

[8] "Experiences With the Introduction of Office Automation," *Monthly Labor Review*, April 1960, pp. 376–380.

[9] Floyd C. Mann, "Psychological and Organizational Impacts," *Automation and Technological Change* (the American Assembly, Columbia University; New York: Prentice Hall, 1962), pp. 43–65.

[10] C. E. Weber, "Impact of Electronic Data Processing on Clerical Skills," *Personnel Administration*, 1959, pp. 20–27.

[11] See, for example, U.S. Department of Labor, Bureau of Labor Statistics, *Automation Opportunities for Office Workers*, Bull. 1241 (Washington: USGPO, 1958); and U.S. Department of Labor, Bureau of Labor Statistics, *Adjustments to the Introduction of Office Automation*, Bull. 1276 (Washington: USGPO, May 1960).

[12] U.S. Department of Labor, Bureau of Labor Statistics, *A Case Study of a Modernized Petroleum Refinery*, BLS Report 120 (Washington: USGPO, 1957).

[13] U.S. Department of Labor; Bureau of Labor Statistics, *A Case Study of a Company Manufacturing Electronic Equipment* ("Studies of Automatic Technology No. 1"; Washington: USGPO, October 1955).

In an excellent study of the pulp and paper industry,[17] the Bureau of Labor Statistics found that while opportunities for semiskilled and unskilled workers were reduced as a result of technological change, administrative, technical, clerical, and supervisory employment was growing. There was a significant reduction in the proportion of laborers who moved materials or manipulated machinery by hand. In the new jobs created, workers were required to oversee a wider expanse of workflow, to relate one step to another, and to regulate operations by pushbutton control. The report contains some very good tables and charts showing changes in occupational distribution resulting from automation.

In banking, the Bureau of Labor Statistics found that the introduction of automatic equipment meant the creation of some new jobs, such as reader-sorter operator, looking-up clerk, and check encoder, while it increased the need for management personnel to control the expanded operations.[18] Some jobs, mainly in the area of demand deposit bookkeeping and processing, were eliminated. Skill requirements were increased for many, with more emphasis upon ability to do technical work with the new electronic data systems.

The Canada Department of Labour, in conjunction with other Canadian Government agencies, has been studying the effects of technological change for many years. As noted in its first report, "The need for a critical examination of changing requirements for skilled manpower in Canadian industries and occupations and for an assessment of available manpower has been increasingly evident during recent years." [19]

In 1956, the Department undertook the Skilled Manpower Training Research Program which involves the study of technological changes in selected industries and their effects on manpower and training requirements. Reports on the following industries have been issued:

(1) Electrical and electronics industry, and heavy machinery industry;
(2) Household appliance industry;
(3) Automobile and parts manufacturing industries;
(4) Electronic data processing industries;
(5) Life insurance industry; and
(6) A special study on education and training of tool and die makers, sheet metalworkers, form molders, draftsmen, and electronic technicians.

This excellent series offers a great deal of information about the changing occupational patterns of individual industries. Relatively little information, however, is available on changes in job content or skill. As one of the Canadian studies indicates,

> In the discussion of occupational changes that have taken place in the industry, changes in content of jobs within an occupational classification have so far been neglected. It is well known that extensive changes do occur in job content, in terms of both duties and skill requirements. Unfortunately, not enough information is available to analyze such changes in any detail. The only instances where these changes are taken into account are those that involve so extensive a change that a new occupational title is created at either the same or a different skill level.[20]

This study does analyze the effects of different technological changes upon manpower, and, wherever possible, indicates the resulting effects upon skill requirements.

A number of special studies have made real contributions in the field of automation and manpower, and James R. Bright and William A. Faunce have done notable work in this field. In examining the actual work performed by persons in various jobs,[21] Bright concluded that there was no uniform pattern of change in skill requirements for various jobs. Automation involved an increase in skill in some jobs but a decrease in skill in others, with an increase in responsibility a more general result. He noted that while some new jobs required superior education and training, or demanded significantly higher levels of comprehension and responsibility, these conclusions did not always hold. Contrary to popular opinion, he found that automated production systems did not create a shortage of new skills or necessitate extensive retraining, but tended to reduce required skill and training. He noted that automation may mean an increase in skill for setup men and technicians, but either no change in skill or a decline for the average worker.

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[14] U.S. Department of Labor, Bureau of Labor Statistics, *The Introduction of an Electronic Computer in a Large Insurance Company* ("Studies of Automatic Technology No. 2"; Washington: USGPO, October 1955).

[15] These two studies are summarized briefly in "Adjustments to Automation in Two Firms," *Monthly Labor Review*, January 1956, pp. 15–19.

[16] U.S. Department of Labor, Bureau of Labor Statistics, *A Case Study of a Large Mechanized Bakery* ("Studies of Automatic Technology No. 3"; Washington: USGPO, September 1956).

[17] U.S. Department of Labor, Bureau of Labor Statistics, *Impact of Technological Change in Automation in the Pulp and Paper Industry* (Bull. 1347, Washington: USGPO, 1962).

[18] Rose Wiener, "Changing Manpower Requirements in Banking," *Monthly Labor Review*, September 1962, pp. 989–995.

[19] Dominion of Canada, Federal Department of Labour, Progress Report, Report No. 1, issued by the Interdepartmental Skilled Manpower Training Research Committee (Ottawa, Department of Labour, June 1957), p. 3.

[20] Dominion of Canada, Federal Department of Labour, *Technological Changes and Skilled Manpower: The Automobile and Parts Manufacturing Industries*, Report No. 8, issued by the Interdepartment Skilled Manpower Training Research Committee (Ottawa, September 1960), p. 24.

[21] James R. Bright, *Automation and Management* (Boston: Harvard University, Graduate School of Business Administration, 1958). See also, Bright, "Does Automation Raise Skill Requirements?" *Harvard Business Review*, July–August 1958, pp. 85–98.

Faunce observed significant changes in the content of jobs in the automobile industry as the result of automation.[22] There were reductions in material handling and the control of work pace, but increases in the attention required as well as a variety of changes in certain skill requirements. After interviewing 125 workers in one of the more highly automated automobile engine plants in Detroit, Faunce concluded that machine operators required somewhat different but probably no greater skills than those in more conventional plants. Elsewhere he noted an increase in the individual worker's responsibility, in many cases because his work now accounted for a larger share of the total production process, and because in most instances investment in machinery per worker and the cost of worker mistakes increased.[23]

In 1957, McGraw-Hill surveyed a sample of metalworking firms with experience with automation and found no uniform reaction to the effects of automation upon skill requirements. Only 27 percent of the sample firms indicated that machine operators needed more skill on automated equipment; 30 percent noted no change in skill requirements; and 43 percent felt that the new operation required less skill.[24]

In a study at a semiautomatic steel mill, Charles R. Walker found that in a number of jobs skill levels did not change but were of a different kind, with more mental skills now compared to hand skills.[25] In a similar vein, Louis E. Davis notes that "under automation, work and jobs at the operator level are so different from modern production jobs that there are no means for making direct comparisons of content of skills."[26] Clearly, however, not all writers agree about the effects of automated equipment on the job content of blue-collar workers. In a very recent study, John J. Macut felt that the job content of machine tool operators declined in skill. As a result of the numerical control of machine tools, merely a machine tender or machine watcher was required. However, a new job of programer was created.[27]

This brief summary of the literature on automation and technological change indicates that the empirical research has been spotty, covering relatively few industries or occupations. Most of it has examined the effects upon employment levels and the occupational structure of plants or industries. Relatively little work has been done on the effects upon job content and skill requirements of occupations made by automation and technological change, and even here, there is far from a general agreement. In some cases, changes have required more skills, in others less; and in other instances one can only say that required skills have changed. The specific effects may vary according to the type of equipment used and the occupations and industry involved. Also, it is imperative to define carefully what is meant by skill level since there are few objective standards for determining narrow differences in skills. Even where it is evident that the content of a job has changed and that skill requirements are different, there is no easy answer to the question of whether the job now requires more or less skill. From the current literature one cannot generalize about the effects of automation and technological change upon job content and skill requirements, except to say that they differ.

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[22] William A. Faunce, "The Automobile Industries: A Case Study in Automation," in H. B. Jacobson and J. S. Roucek (eds.), *Automation and Society* (New York, Philosophical Library, 1959), pp. 44–53.

[23] William A. Faunce, "Automation and the Automobile Worker," *Social Problems*, Summer 1958, pp. 68–78.

[24] These figures were published in *American Machinist*, October 21, 1957.

[25] Charles R. Walker, "Life in the Automatic Factory," *Harvard Business Review*, January–February 1958, pp. 111–119.

[26] Louis E. Davis, "The Effects of Automation on Job Design," *Industrial Relations*, October 1962, p. 70.

[27] John J. Macut, "New Technology in Metal Working," *Occupational Outlook Quarterly*, February 1965, pp. 1–6.

2. Scope of the Research

The major concern of this study is the impact of automation and technological change on the content and skill requirements of specific occupations in selected industries. Despite its connotations, this is a relatively narrow problem in the broad field of the effects of automation and technological change on manpower and employment.

Various studies and articles deal with the impact of technological change upon total employment, job opportunities of workers at different skill levels, and occupational structures of various industries. While the significance of some of the studies cited in the previous section is unclear, several make possible a better understanding of the impact of technological change upon the opportunities that workers at different skill levels may have in the economy as a whole or in specific industries.

A great deal of the literature on technological change is concerned with the impact upon employment and employment opportunities, or upon the employment distribution among occupations or different skill levels. Occupations need not change, but a shift in the job mix may mean more job opportunities for skilled workers and fewer opportunities for unskilled, or the reverse. Any one of numerous combinations is possible while the content of jobs and skill requirements of jobs remain unchanged. Job opportunities may also change as a result of the creation of new occupations or the elimination of old ones.

A change in skill requirements can result from two distinct developments: One is a change in the distribution of employment among jobs in a given occupational structure, including the elimination of some occupations. The other is a change in the content and potential skill levels of existing occupations, and the creation of new occupations. In the first case, new occupations or changes in content occur only as the result of job obsolescence; yet, the number of workers employed at different skill levels can change. In the second case, no change in the distribution of employment among jobs need occur, except as the result of new changes; nevertheless, the number of workers employed at different skill levels also can change. Both types of changes probably occur simultaneously. In the short run, the first probably predominates; over longer periods, the second becomes more important.

Here we are concerned solely with the second type of change. Most of the studies examined in the previous section dealt with the first kind; some combined both the first and the second without determining the relative importance of each; a few were restricted to the second but inferred that changes in content alone were responsible for changes in skill levels.

Distinguishing between these two types of changes can avoid some serious errors about future skill needs. It is quite possible for a significant change in skill requirements to occur without any change in job content, if the distribution of employment changes substantially. On the other hand, important changes in content can occur without any meaningful change in overall skill requirements. This is possible if offsetting changes in the distribution of employment occur or if a change in one occupation is offset by an opposite change in another employing the same number of workers.

In general, our analysis may lead to a better understanding of the changes in the complexity of work performed in American industry. In many cases it was possible to isolate technological change as the specific cause of such changes in complexity. This project may also shed some light on an important factor which affects the occupational composition of a work force; however, our study does not analyze the occupational composition of that work force. Occupational composition involves the number of people employed in each job, and this composition may change without any change in the kinds of occupations in existence in an industry. Our current research project, therefore, is limited to the content of occupations and an analysis of newly created occupations and those which have disappeared since 1949.

3. Methodology of the Industry Studies

We have studied changes over the last 15 years in work content and in traits and preparation required of workers in five industries (or activities) selected in as wide a range as possible in the hope that conclusions may be applicable to American industry as a whole. These changes, as well as a picture of the current structure of work complexity in the occupations of these industries, are presumed to indicate some of the results of the impact of technology on skill levels. Occupational descriptions and analyses of the U.S. Bureau of Employment Security are the sources.

The three manufacturing and two nonmanufacturing industries studied have undergone or are undergoing significant changes in processes, products, or both.[1] The manufacturing industries are slaughtering and meatpacking, rubber tires and tubes, and machine shop trades. The nonmanufacturing industries are medical services and banking.[2] Occupations covered in the three manufacturing industries are chiefly manual and supervisory; in banking, white-collar; and in medical services, professional, technical, and service. Except for occupations in banking, those studied are peculiar to the industries or trades selected. Banking, however, includes many office occupations prevalent in other industries, and thus automatically is an occupational rather than a more restricted industrial study. Similarly, machine shop trades are occupational rather than industrial in scope.

There are two basic reasons for assuming that developments in technology, broadly defined to include the introduction of new as well as the spread of older machinery and organization, are responsible for changes in skill levels. First, 15 years is long enough time to rule out temporary factors associated with changes. Second, occupations were chosen on the basis of an industry or trade, rather than an individual firm, thus ruling out differences in work methods resulting from variations in managerial competency or technical progressiveness.

Three sources of information are used: First, definitions or descriptions of occupational titles in the second edition of the *Dictionary of Occupational Titles* (D.O.T.) and its two supplements;[3] second, the definitions and descriptions of the occupational titles to be included in the forthcoming third edition of the D.O.T.,[4] which also evaluate (1) the traits workers need to learn and perform satisfactorily the work covered by each title, as well as (2) the level of complexity of the occupation as indicated by so-called worker functions; and third, the *Estimates of Worker Trait Requirements for 4,000 Jobs as Defined in the Dictionary of Occupational Titles*,[5] which lists the traits required by titles described in the second edition of the D.O.T., presumably for the year 1949.

The *Dictionary of Occupational Titles* was first published in 1939 by the Bureau of Employment Security; in 1949, a revised edition was made available. The principal purpose of the D.O.T., which catalogs all occupations and their job content in a formal structure, was to assist placement officers of local employment service offices throughout the country to make rational and objective placements.

Many changes have occured in our economy since 1949. Industry structures have changed, some to a minor degree, while others fairly drastically. Old firms have disappeared; new firms have been established. Some industries have contracted; other have expanded greatly. Some products have become obsolete; a significant number of new products have been introduced. All these changes have had an important impact upon the occupational needs of our economy. In addition, a technological revolution of some sort has occurred during the past 15 years—whether minor or major is moot. However, while some occupations have remained unchanged, others have been changed slightly, still others have been changed drastically, and some have even disappeared completely. Now, after a number of years of work, a thoroughly revised *Dictionary of Occupational Titles* is due with an up-to-date analysis of occupations.

Thus, for the five selected industries, our study analyzes the changes in job content of occupations that have occurred between 1949 and 1965, the dates of publication of the second and third editions of the D.O.T. For each industry, we examined the lists used by the Bureau of Employment Security to develop the occupational structure for the D.O.T. From these, we were able to determine which occupations have been created since 1949, which no longer exist, and those whose job title has changed as a result of significant changes in job content. We are aware that only narrow conclusions can be drawn from such an analysis, and one cannot always be certain that the changes are the results of technological changes or other factors. Clearly this type of analysis involves a great deal of subjective judgment, a judgment which, however, was tempered by a careful analysis of the data and considerable experience with occupational descriptions and job content.

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[1] See, for example, U.S. Department of Labor, Bureau of Labor Statistics, *Technological Trends in 36 Major American Industries*, a study prepared for the President's Committee on Labor-Management Policy (Washington: n.d.); and John J. Macut, *loc.cit.*

[2] Industrial designations are those used by the U.S. Bureau of Employment Security for purposes of occupational analysis, and differ from those of the *Standard Industrial Classification* of the U.S. Bureau of the Budget.

[3] U.S. Employment Service, Division of Occupational Analysis, *Dictionary of Occupational Titles: Definitions of Titles* (2d ed., Washington: USGPO, March 1949); *Supplement 1* (2d ed., March 1955); and *Dictionary of Occupational Titles*, Unpublished Definitions (3 pts., n.d.). *Supplement 1* is bound; the second is a collection of mimeographed titles and descriptions in looseleaf form. Definitions included in our report are "coded definitions" that represent "distinct jobs or sets of duties." Classification titles, that is, coded definitions that do not represent distinct jobs or sets of duties, are not included. For an explanation of these terms, see *Dictionary of Occupational Titles: Definitions of Titles*, p. xvi.

[4] These definitions were made available in advance of publication by the U.S. Employment Service, Bureau of Employment Security. The new edition was published subsequent to the writing of this paper.

[5] U.S. Employment Service (Washington: USGPO, 1950).

A thorough analysis was made of those occupations peculiar to the selected industries, and for this reason it was not always possible to obtain complete data for all possible occupations in an industry for both time periods. Occupations such as "clerk" or "programer" which cut across industry lines are not listed as specific to any one industry. Nevertheless, some analysis was made of a number of such white-collar occupations.

For all occupations which existed in both 1949 and 1965, job descriptions for the two periods were compared carefully. It was possible to determine with a reasonably high degree of accuracy whether any basic changes took place in work content, and whether these changes raised, lowered, or did not change skill requirements. In some cases it was exceedingly difficult, if not impossible, to determine whether the change in content meant higher or lower skill requirements. In others, the changes in job content were of a minor nature, perhaps just in the word description. In addition, worker trait requirements published in 1950 in *Estimates of Worker Trait Requirements for 4,000 Jobs as Defined in the Dictionary of Occupational Titles* were compared with those prepared for the new 1965 edition of the *Dictionary of Occupational Titles*, when these were available. Thus, for many jobs we were able to analyze the changes in the requirements of education, temperament, and aptitudes, and also the kinds of work performed.

The worker traits refer to general educational development (GED), specific vocational preparation (SVP), 11 aptitudes, and 12 possible temperaments required by workers for successful work performance.[6] Three of the aptitudes constitute a group dealing with intelligence (GVN). There are six possible levels or rankings of educational development (also referred to as educational requirements), nine of vocational preparation (also called training requirements), and five for each of the aptitudes. The temperaments have no rankings but can be combined in various ways to summarize certain personality characteristics, which in turn suggest the nature of the work and its skill level. Although the worker traits refer to personal attributes, changes in these traits reflect changes in work content and work requirements. In turn, these changes can be interpreted as changes in skill levels resulting from technological developments. Changes in education, training, and aptitudes are indicated by changes in rankings; changes in temperaments, by the addition or elimination of individual temperaments.

The educational requirement rankings cannot be readily translated into equivalent levels of formal education, except perhaps at the upper and lower limits.[7] However, changes in educational requirements undoubtedly reflect changes in levels of formal education, although the exact amounts cannot be specified unless certain assumptions are made about the relationship between each GED level and years of schooling. In contrast, training requirements are defined in terms of specific time intervals, and relevant levels of formal training, including schooling, can be translated into vocational needs.

Worker functions rank occupational titles according to the complexity of the work performed. Each worker function is a rank or step within one of three hierarchies of activities to which it belongs, depending on whether it involves things (e.g., machinery), data (e.g., paperwork), or people (e.g., teaching). The complexity of the work content of a title thus can be indicated by assigning the appropriate worker functions and specifying the proportion of time devoted to them. Worker functions, available only for titles included in the new D.O.T., provide a picture of the skill structure of current titles. Under certain circumstances, this profile can indicate whether or not changes in work requirements have had a significant effect on skill levels. For example, if skill levels are known to be low and the current structure of worker functions shows a predominance of low-skilled titles, there could not have been much upward movement over the period involved.

Detailed descriptions of each worker trait and its possible rankings, as well as of worker functions, are presented in section 5.

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[6] Traits also include physical capacities and working conditions, but these are not investigated in this study. The worker traits are explained in a series of multilithed publications of the U.S. Bureau of Employment Security. See Department of Labor, Bureau of Employment Security, *Dictionary of Occupational Titles: Proposed Occupational Classification Structure, Appendix C, The Worker Trait Components*, August 1960.

[7] We have interpreted level 2 as requiring less than a high school diploma and perhaps no high school at all; level 3, as at least some high school and perhaps a diploma. The Bureau of Employment Security pointedly refuses to draw such relationships, however.

The method of analysis includes the following four basic steps:

(1) Identify occupational titles peculiar to each of the selected industries which have been eliminated from the third edition of the D.O.T. as obsolete, added as new, or carried over (continued) from the second edition;

(2) Identify changes in the educational, training, aptitudinal, and temperamental requirements of continuing titles (i.e., those included in both editions);

(3) Identify changes in occupational content by comparing changes in the descriptions of the continuing titles; and

(4) Classify occupational titles in each industry by the level of complexity of the occupations.

Occupational titles for the new edition are arranged by industry or activity, with new and obsolete titles identified. For purposes of this report, new titles are those included in the third edition of the D.O.T. but not in the second, even though they may appear in supplements to the second. Obsolete titles, considerably fewer than expected, are those in the second edition and its supplements but no longer in existence, in the sense that employers no longer seek individuals to fill jobs covered by those occupational titles.

The definitions for the second edition were prepared from establishment surveys conducted in the middle and late 1940's; those of the third edition, from surveys conducted in the first half of the 1960's. Comparisons of definitions included in both editions thus illustrate how work content or duties have changed over a 15-year period. Similarly, comparisons of worker traits needed for occupations in the second and third editions show the changes that have occurred in these requirements over the same interval. Both sets of comparisons indicate how skill levels have changed, presumably as a result of changing technology in the industries studied. It also is necessary to compare the traits and descriptions of new titles with those of obsolete and continuing titles in order to complete the picture of the trend in skill levels and the thrust of technology. Each industry differs with respect to the proportion of titles with two sets of traits available. However, the combined use of changes in traits and descriptions provides enough information to permit conclusions about occupations peculiar to the industries or trades examined.

To summarize, the purpose of the industry studies is to determine how skill requirements have changed since the immediate postwar period, the assumption being that these reflect changes in technology broadly defined. Occupations unique to each industry were provided by the Bureau of Employment Security which distinguished between new, obsolete, and continuing occupations. Changes in skill levels are inferred from changes in skill requirements, which are derived from the analysis of (1) worker traits of occupational titles; (2) occupational descriptions; and (3) worker functions. The very few obsolete occupations precluded meaningful comparisons between these and other occupations.

Each industry study contains six sections: Three comparing worker traits, one comparing occupational descriptions, another one describing the current structure of worker functions, and a sixth briefly summarizing the findings regarding the overall skill level in the industry or trade. Two basic types of worker traits comparisons are used: One shows the differences between the traits of new and continuing occupational titles; the other shows the changes in traits of continuing titles; both provide evidence of past changes in skill levels and offer clues about future changes. Comparisons of occupational descriptions show the nature of changes in work content and skill levels independently of changes in traits. These comparisons also are necessary supplements to the worker traits comparisons because the latter are not possible for all continuing titles. Only current titles have worker function designations. However, they give some idea of the current pattern of skills in the industries studied and allow some inferences about the pace of past changes in skill levels, provided the original level of skills in the industry is known. In addition, comparing current worker functions of new and continuing titles indicates possible effects of technology in the future.

4. Limitations of Worker Traits and Functions

There are certain limitations to using worker traits and functions as evidence of changes in skills and technology. First, improvements have occurred since the 1940's in occupational analysis and description; for example, the definitions in the new third edition of the D.O.T. probably are superior to those in the second. Changes in occupational descriptions and traits may thus reflect better information, and not changes in actual content or requirements. Those that do appear probably exaggerate the amount of actual change.

Second, while the new edition contains titles for many new jobs, the total number of titles is substantially fewer than the old. This reflects in some cases a consolidation of old titles that incorporate the same content, thus bringing titles more in line with present-day allocation of duties. The net effect, however, may tend to exaggerate the actual amount of change in content.

Third, the aptitudinal requirements of titles can conceal absolute changes because the levels or ranks are based upon the extent to which they are possessed by different proportions of the working population. If the overall level of the working population has increased, a change in the level of any one title may understate the absolute change required.

Fourth, education and training requirements are supposed to reflect only those needed for average performance of the specific title and not others, such as those higher up on the ladder of promotion. However, to some unknown extent, these requirements probably reflect the generally higher educational attainment of the population as a whole, as well as employer hiring specifications based upon considerations other than the requirements of a specific job. Thus, educational requirements specified for a particular title are probably overstated in terms of those needed to perform that specific job satisfactorily.[1]

Fifth, worker functions, and to a lesser degree the rankings of worker traits, are gross and do not permit fine distinctions. For example, one worker function involving things is "driving-controlling"; this presumably applies equally to the locomotive engineer, airline pilot, bulldozer operator, and taxi driver.

Finally, the occupational descriptions and codes of the U.S. Bureau of Employment Security are designed to help placement interviewers counsel jobseekers and not to measure the changing structure of skills in the economy, much less the consequences of technology. Nevertheless, the occupational material of the Bureau is the only collection of descriptions and traits that is national in scope. It covers entire industries and permits comparisons over many years. Its comprehensiveness and timespan have to be weighed against questions of interpretation and reliability. In our judgment, the advantages outweigh the disadvantages.

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[1] A further difficulty, but not necessarily a limitation as evidence of changes in skills and technology, is that educational requirements are not expressed in terms of formal levels of schooling, even though employers are likely to formulate their hiring specifications this way. A change in educational requirements, thus, is difficult to relate to particular years of schooling or to translate into hiring specifications.

5. Descriptions of Worker Traits and Functions

The definitions of worker traits and worker functions of the Bureau of Employment Security are quoted almost without change for the sake of accuracy and brevity.[1] The Bureau's definitions of worker temperaments, however, are introduced by simple titles originated by the authors for easier identification in later discussion.

Worker Traits

A. *General Educational Development* [2] (GED) "embraces those aspects of education (formal and informal) which contribute to the worker's reasoning development and ability to follow instructions, and [to his] acquisition of 'tool' knowledges such as languages and mathematical skills. [It is] general education [without any] recognized, fairly specific occupational objective [that is] ordinarily obtained in elementary school, high school or college [but which] can be obtained from experience and self-study [as well]."

The six levels of general educational development, arranged from high to low, are defined by the Bureau in terms of reasoning, mathematical, and language development, as follows:

> *Level 6.* Reasoning Development: Apply principles of logical or scientific thinking to a wide range of intellectual and practical problems. Deal with nonverbal symbolism (formulas, scientific equations, graphs, musical notes, etc.) in its most difficult phases. Deal with a variety of abstract and concrete variables. Apprehend the most abstruse classes of concepts.
>
> Mathematical Development: Applies knowledge of advanced mathematical and statistical techniques, such as differential and integral calculus, factor analysis, and probability determination, or works with a wide variety of theoretical mathematical concepts and makes original applications of mathematical procedures, as in empirical and differential equations.
>
> Language Development: Comprehension and expression of a level to (1) report, write, or edit articles for such publications as newspapers, magazines, technical or scientific journals; (2) prepare and draw up deeds, leases, wills, mortgages and contracts; (3) prepare and deliver lectures on politics, economics, education, or science; (4) interview, counsel, or advise people, such as students, clients or patients, in such matters as welfare eligibility, vocational rehabilitation, mental hygiene, or marital relations; or (5) evaluate engineering technical data to design buildings and bridges. [Numbers not in original text.]
>
> *Level 5.* Reasoning Development: Apply principles of logical or scientific thinking to define problems, collect data, establish facts, and draw valid conclusions. Interpret an extensive variety of technical instructions, in books, manuals, mathematical, or diagrammatic form. Deal with several abstract and concrete variables.
>
> Mathematical and Language Development are the same as in Level 6.
>
> *Level 4.* Reasoning Development: Apply principles of rational systems to solve practical problems and deal with a variety of concrete variables in situations where only limited standardization exists. Interpret a variety of instructions furnished in written, oral, diagrammatic, or schedule form. Principles of rational systems [include] bookkeeping, internal combustion engines, electric wiring systems, house building, nursing, farm management, ship sailing.
>
> Mathematical Development: Perform ordinary arithmetic, algebraic, and geometric procedures in standard, practical applications.
>
> Language Development: Comprehension and expression of a level to (1) transcribe dictation, make appointments for executive and handle his personal mail, interview and screen people wishing to speak to him, write routine correspondence on own initiative; (2) interview job applicants to determine work best suited for their abilities and experience, contact employers to sell them services of an agency; or (3) interpret technical manuals as well as drawings and specifications such as layouts, blueprints, and schematics. [Numbers not in original text.]
>
> *Level 3.* Reasoning Development: Apply commonsense understanding to carry out instructions furnished in written, oral, or diagrammatic form. Deal with problems involving several concrete variables in or from standardized situations.
>
> Mathematical Development: Make arithmetic calculations involving fractions, decimals, and percentages.
>
> Language Development: Comprehension and expression of a level to (1) file, post, and mail such material as forms, checks, receipts, and bills; (2) copy data from one record to another, fill in report forms, and type all work from rough draft or corrected copy; (3) interview members of household to obtain information such as age, occupation, and number of children, to be used as data for surveys, or economic studies; or (4) guide people on tours through historical or public buildings, describing various aspects

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[1] Taken from *Dictionary of Occupational Titles: Proposed Occupational Classification Structure, Appendix C, The Worker Trait Components, op. cit.;* U.S. Bureau of Employment Security, U.S. Employment Service, *Aptitude Manual,* March 1961; Department of Labor, Bureau of Employment Security, U.S. Employment Service, *Work Performed Manual,* September 1959; and Department of Labor, Bureau of Employment Security, *Functional Occupational Classification Program; Worker Traits Manuals; Training Time, A—General Educational Development, B—Specific Vocational Preparation (Revised 1959),* July 1959.

[2] This and *Specific Vocational Preparation* comprise "Training Time," defined as the educational development and vocational preparation "required for a worker to acquire the knowledges and abilities necessary for average performance in a particular job-worker situation." See *Dictionary of Occupational Titles: Proposed Occupational Classification Structure, appendix C, op. cit.,* p. 1.

such as size, or value, points of interest. [Numbers not in original text.]

Level 2. Reasoning Development: Apply commonsense understanding to carry out detailed but uninvolved written or oral instructions. Deal with problems involving a few concrete variables in or from standardized situations.

Mathematical Development: Use arithmetic to add, subtract, multiply, and divide whole numbers.

Language Development is the same as in Level 3.

Level 1. Reasoning Development: Apply commonsense understanding to carry out single one- or two-step instructions. Deal with standardized situations with occasional or no variables in or from those situations encountered on the job.

Mathematical Development: Perform simple adding and subtracting (or reading and copying of figures or counting and recording).

Language Development: Comprehension and expression of a level to (1) learn job duties from oral instructions or demonstration; (2) write identifying information such as name and address of customer, weight, number, or type of product, on tags or slips; or (3) request orally, or in writing, supplies such as linen, soap, or work materials. [Numbers not in original text.]

The General Educational Development scale for ranking titles differs in the second and third edition of the D.O.T., the new scale combining the two lowest ranks of the old. This difference is taken into account when making comparisons, which are described in terms of the new scale. The new scale also combines some of the rankings of the former mathematical and language development scales, but without invalidating comparisons. The new scale of mathematical development combines the two highest ranks of the old, while the new scale of language development combines the two top ranks in one group, and the third and fourth ranks in another.

B. *Specific Vocational Preparation* (SVP), is the "amount of time required to learn the techniques, acquire the information, and develop the facility needed for average performance in a specific job-worker situation. This training can be acquired in a school, work, military, institutional, or avocational environment. [Excluded is] orientation training [needed by] even a fully qualified worker [to become used to] the special conditions of any new job." Included are formal vocational education, apprentice training, organized inplant instruction, on-the-job training under a qualified worker, and "essential experience" in "less responsible jobs" in a line of promotion. Thirty hours of high school, shop, or commercial training is equal to 15 hours of on-the-job training; the "average" 4-year nonliberal arts college curriculum, to 2 years' vocational preparation; and each year of graduate school, to 1 year of vocational preparation. In the old scale, 4 years of college is equal to 2 years of general educational development as well; the new scale avoids explicit connection between formal schooling and educational development.

The nine levels of Specific Vocational Preparation, arranged from low to high, are:

Level 1—short demonstration only
Level 2—anything beyond short demonstration up to and including 30 days
Level 3—over 30 days up to and including 3 months
Level 4—over 3 months up to and including 6 months
Level 5—over 6 months up to and including 1 year
Level 6—over 1 year up to and including 2 years
Level 7—over 2 years up to and including 4 years
Level 8—over 4 years up to and including 10 years
Level 9—over 10 years

C. *Aptitudes* are "the specific capacities or abilities required of an individual . . . to facilitate the learning of some task or job duty."[3] Some are mental, some perceptive, and others manual. Their titles, letter symbols, and Bureau definitions follow:

1. *Intelligence* (G), or general learning ability, "is the capacity to 'catch on' or understand instructions and underlying principle . . . to reason and make judgments and is closely related to doing well in school."

2. *Verbal* (V) is the "ability to understand meanings of words and ideas associated with them and to use them effectively. [It involves comprehension of] language . . . relationships between words . . . and meanings of whole sentences and paragraphs, [as well as the ability to] present information or ideas clearly."

3. *Numerical* (N) is the "ability to perform arithmetic operations quickly and accurately."

4. *Spatial* (S) is the "ability to comprehend forms in space and understand relationships of plane and solid objects and may be used to read blueprints and solve geometry problems. It often is described as the ability to 'visualize' objects of two or three dimensions or to think visually of geometric forms."

5. *Form Perception* (P) is the "ability to perceive pertinent detail in objects or in pictorial or graphic material [and] make visual comparisons and discriminations and see slight differences in shapes and shadings of figures and widths and length of lines."

6. *Clerical Perception* (Q) is the "ability to perceive pertinent detail in verbal or tabular material . . . observe differences in copy . . . proofread words and numbers, and . . . avoid perceptual errors in arithmetic computation."

7. *Motor Coordination* (K) is the "ability to coordinate eyes and hands or fingers rapidly and accurately in making precise movements with

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[3] *Aptitude Manual, op. cit.*, p. 1.

speed [and] make a movement response accurately and quickly."

8. *Finger Dexterity* (F) is the "ability to move the fingers and manipulate small objects with the fingers rapidly or accurately."

9. *Manual Dexterity* (M) is the "ability to move the hands easily and skillfully [and] to work with the hands in placing and turning motions."

10. *Eye-Hand-Foot Coordination* (E) is the "ability to move the hand and foot coordinately with each other in accordance with visual stimuli."

11. *Color Discrimination* (C) is the "ability to perceive or recognize similarities or other values of the same color . . . identify a particular color, or . . . recognize harmonious or contrasting color combinations, or . . . match colors accurately."

Each aptitude has a rating that shows the "amount" needed for satisfactory, that is, "average" performance. This amount is "expressed in terms of equivalent amounts possessed by segments of the general working population" according to the following scale:

> (1) The top 10 percent of the population, [that is, those having an] extremely high degree of the aptitude;
>
> (2) The highest third exclusive of the top 10 percent, [or those having an] above average or high degree of the aptitude;
>
> (3) The middle third of the population, [or those having a] medium degree of the aptitude, ranging from slightly below to slightly above average;
>
> (4) The lowest third exclusive of the bottom 10 percent [or those having a] below average or low degree of the aptitude;
>
> (5) The lowest 10 percent, [or those having a] negligible degree of the aptitude.

In this paper, aptitude ratings of 1 and 2 often are above average or superior; a rating of 3 is average; and ratings of 4 and 5 are below average or inferior.

D. *Temperaments* are personality dispositions that complement the particular conditions or tasks of a work situation and are defined in these terms. The appropriate conditions and tasks are specified after the identifying titles. (Titles are not terminology of the Bureau of Employment Security.)

1. *Variation* refers to "a variety of duties often characterized by frequent change."

2. *Repetitiveness* refers to "repetitive or short-cycle operations carried out according to set procedures or sequences."

3. *No Discretion* refers to "doing things only under specific instruction, allowing little or no room for independent action or judgment in working out job problems."

4. *Directing* refers to "the direction, control, and planning of an entire activity or the activities of others."

5. *Dealing with people* refers to "the necessity of dealing with people in actual job duties beyond giving and receiving instructions."

6. *Working Alone* refers to "working alone . . . in physical isolation . . . although [the] activity may be integrated with that of others."

7. *Influencing People* refers to "influencing people in their opinions, attitudes, or judgments . . . ."

8. *Emergencies* refers to "performing adequately under stress when confronted with the critical or unexpected or taking of risks."

9. *Evaluation* refers to "the evaluation (arriving at generalizations, judgments, or decisions) of information against sensory or judgmental criteria" or against "measurable or verifiable criteria."[4]

10. *Interpretation* refers to personal "interpretations of feelings, ideas, or facts . . . ."

11. *Precision* refers to "the precise attainment of set limits, tolerances, or standards."

Worker Functions

The worker functions[5] are "activities used to identify worker relationships to things, data, and people. [The relationships] can be arranged from the simple to the complex in . . . a hierarchy so that each successive function includes the simpler functions and excludes the more complex. . . . The degree of involvement with things, data, and people [or their] relative importance . . . can be expressed by weights from 1 to 8 so that they total 10."

A. "*Things Functions*," as defined by the Bureau, include the following manual activities, beginning with the least complex and becoming successively more so:

1. *Handling*, which is "using body members, handtools, and/or special devices to work, move, or carry objects or materials and . . . involves little or no latitude for judgment with regard to attainment of standards or . . . selecting [the] appropriate tool, object, or materials;"

2. *Feeding-Offbearing*, which is "inserting, throwing, dumping, or placing materials in or removing them from machines or equipment which are automatic, or tended, or operated by other workers;"

3. *Tending*, which is "starting, stopping, and observing the functioning of machines and equipment . . . and involves adjusting material or controls of the machine, requiring 'little judgment,' such as changing guides, adjusting timers and temperature gauges, turning valves to allow flow

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[4] Two separate temperaments are combined, the one evaluation based on subjective criteria and the other, on objective criteria.

[5] Taken from *Work Performed Manual, op. cit.*, p. 8 and appendix A.

of materials, and flipping switches in response to lights;"

4. *Manipulating*, which is "using body members, tools, or special devices to work, move, guide, or place objects or materials, and involving some latitude for judgment with regard to precision attained and selecting the appropriate tool, object, or material, although this is readily manifest;"

5. *Operating-Controlling*, which is "starting, stopping, controlling and adjusting the progress of machines or equipment designed to fabricate and/or process things, data, or people [and includes] setting up the machine and adjustment of the machine or material as the work progresses . . . observing gauges, dials, etc., and turning valves and other devices to control such items as temperature, pressure, flow of liquids, speed of pumps, and reactions of materials [with the setup involving] several variables [and] adjustment . . . more frequent than in tending;"

6. *Driving-Controlling*, which is "starting, stopping, and controlling the actions of machines for which a course must be steered or guided in order to fabricate, process, and/or move things or people [excluding] such manually powered machines as hand trucks and dollies;"

7. *Precision Working*, which is "using body members and/or tools, or work aides to work, move, guide, or place objects or materials in situations where ultimate responsibility for the attainment of standards occurs and selection of appropriate tools, objects, or material, and the adjustment of the tool to the task require exercise of considerable judgment;"

8. *Setting Up*, which is "adjusting machines or equipment by replacing or altering tools, jigs, fixtures, attachments to prepare them to perform their functions, change their performance, or restore their proper functions if they break down [and covers] workers who set up one or more machines for other workers or who set up and personally operate a variety of machines. . . ."

The principal criteria for distinguishing the feeding-offbearing, tending, operating-controlling, and setting-up function from each other are "latitude of judgment; selection of the appropriate tool, object, or material and standards to be attained; and the responsibility involved." For purposes of this report, handling, feeding-offbearing, and tending are considered low-skilled; manipulating, operating-controlling, and drive-controlling, medium skilled; and the other functions, high skilled.

B. "*Data Functions*" include the following, beginning with the least complex:

1. *Comparing*, which is "judging the readily observable functional, structural, or compositional characteristics (whether similar to or divergent from obvious standards) of things, data, or people;"

2. *Copying*, which is "transcribing, entering, or posting data;"

3. *Computing*, which is "performing arithmetic operations and reporting on and/or carrying out a prescribed action in relation to them [but excluding] counting;"

4. *Compiling*, which is "gathering, collating, or classifying information about things, data, or people [and] frequently [includes] reporting and/or carrying out a prescribed action in relation to it . . .;"

5. *Analyzing*, which is "examining and evaluating data [and] frequently [includes] presenting alternative actions . . .;"

6. *Coordinating*, which is "determining time, place, and sequence of operations, or action to be taken on basis of analysis of data; executing determinations and/or reporting on events;"

7. *Synthesizing*, which is "integrating analyses of data to discover facts and/or develop knowledge, concepts of interpretations."

For purposes of this report, comparing and copying are considered low skilled; computing and compiling, medium skilled; and the others, high skilled.

C. "*People Functions*" include the following, going from the least to the most complex:

1. *Taking Instructions-Helping*, which is "attending to the work assignment instructions or orders of supervisors . . . [and applying to] nonlearning helpers;"

2. *Serving*, which is "attending to the needs or requests of people or animals or expressed or implicit wishes of people [involving an] immediate response;"

3. *Speaking-Signaling*, which is "talking, conversing with, and/or signaling people to convey or exchange information;"

4. (a) *Persuading*, which is "influencing others in favor of a product, service, or point of view;

(b) *Diverting*, which is "amusing others;"[6]

5. (a) *Supervising*, which is "determining or interpreting work procedure for a group of workers, assigning specific duties to them, maintaining harmonious relations among them, and promoting efficiency;"

(b) *Instructing*, which is "teaching subject matter to others, or training others (including animals) through explanation, demonstrations, and supervised practice; or making recommendations on the basis of technical disciplines;"

6. *Negotiating*, which is "exchanging ideas, information, and opinions with others to formulate

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[6] Persuading and Diverting are on the same level of complexity.

policies and programs and/or arrive jointly at decisions, conclusions, or solutions to problems;"

7. *Mentoring*, which is "dealing with individuals in terms of their total personality in order to advise, counsel, and/or guide them with regard to problems that may be resolved by legal, scientific, clinical, spiritual, and/or other professional principles."

In this report, taking instruction-helping, serving, and speaking-signaling are considered low skilled; persuading and diverting, medium skilled; and the rest, high skilled.

6. Industry Studies

Slaughtering and Meatpacking

Educational and Training Requirements

Almost all the titles peculiar to slaughtering and meatpacking are manual and require little educational development or vocational preparation (see tables S–1 to S–3). Nearly 70 percent of the titles are unskilled; a few over 20 percent are semiskilled; and only about 7 percent are skilled. Ninety percent currently need no more than a second level of educational development (equivalent to less than high school, if that much); three-fifths need no more than 30 days' vocational training; 16 percent, no more than 3 months.

In general, the unskilled and semiskilled titles require little education or training, and about half of the skilled do not require much more. Ninety percent of the unskilled and over four-fifths of the semiskilled titles, as well as half the skilled, require no more than a second level of education. Over four-fifths of the semiskilled titles need no more than a month or from 1 to 3 months' training; and nearly 90 percent of the unskilled need no more than a month. Training requirements of the skilled titles are more varied. Two skilled titles require at least 2 years, while the other five require either no more than 6 months or no more than a year.

On balance, educational and training requirements seem to have risen little if at all since the early postwar years[1] (see tables S–4 to S–6). Of the 107 continuing titles, only 29 have 2 sets of worker traits data. These relatively few continuing titles are concentrated at educational level 2 and at a vocational preparation level of 1 to 3 months. There were net decreases in the number of titles at educational levels 1, 3, and 4, accompanied by a net increase in those at level 2. Similarly, there were net decreases in the number of titles requiring preparation of no more than a month, 3 to 6 months, 1 to 2 years, and 2 to 4 years, and a net increase in the number requiring only 1 to 3 months. There are currently fewer titles needing almost no education and training or moderate amounts, but more needing only "a little" of either. However, the net increases in educational levels outnumber the net decreases, while the net decreases in training levels outnumber the net increases.

There were just 12 new titles, too few to shed much more light on the matter. Six of these 12 were unskilled requiring limited education (only level 2) or training (4 titles needing no more than a month, and 2 no more than 3 months) (see tables S–1 to S–3). Two others were semiskilled and both needed little education (level 2) while one needed little training as well (not over 3 months). The other four were foreman occupations specified by the type of activity or department; they required fourth level education (equivalent to at least high school) and over 2 years' training. It is questionable if these titles actually are new to the industry; they simply may reflect more accurate occupational reporting or analysis.

Aptitudinal Requirements

A large majority of the titles now call for below average abilities in every aptitude except manual dexterity and motor coordination, and there is little evidence that the current picture differs substantially from that of 10 or 15 years earlier.

TABLE S–1. CURRENT EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

GED–SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1–1	10	9.3	0	0	10	8.4
1–2	10	9.3	0	0	10	8.4
1–3	2	1.9	0	0	2	1.7
2–1	4	3.7	2	16.7	6	5.0
2–2	53	49.5	3	25.0	56	47.1
2–3	14	13.1	2	16.7	16	13.4
2–4	4	3.7	0	0	4	3.4
2–5	2	1.9	1	8.3	3	2.5
3–3	2	1.9	0	0	2	1.7
3–4	2	1.9	0	0	2	1.7
3–5	1	.9	0	0	1	.8
4–5	1	.9	0	0	1	.8
4–6	0	0	0	0	0	0
4–7	1	.9	3	25.0	4	3.4
4–8	1	.9	1	8.3	2	1.7
Total[1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE S–2. CURRENT EDUCATIONAL REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

GED level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	22	20.6	0	0	22	18.5
2	77	71.9	8	66.7	85	71.4
3	5	4.7	0	0	5	4.2
4	3	2.8	4	33.3	7	5.9
Total	107	100.0	12	100.0	119	100.0

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[1] The changes are so varied and so minor that it is even possible for the educational and training requirements to have fallen.

TABLE S-3. CURRENT TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	14	13.1	2	16.7	16	13.5
2	63	58.9	3	25.0	66	55.5
3	18	16.9	2	16.7	20	16.8
4	6	5.6	0	0	6	5.0
5	4	3.7	4	33.3	8	6.7
6	0	0	0	0	0	0
7	1	.9	0	0	1	.8
8	1	.9	1	8.3	2	1.7
Total	107	100.0	12	100.0	119	100.0

TABLE S-4. NET CHANGE IN EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

GED-SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1-2	10	34.5	1	3.4	−9
1-3	0	0	1	3.4	+1
2-2	6	20.7	12	41.4	+6
2-3	2	6.9	10	34.5	+2
2-4	3	10.4	1	3.4	−2
2-5	2	6.9	1	3.4	−1
3-3	1	3.4	0	0	−1
3-4	2	6.9	1	3.4	−1
3-5	0	0	1	3.4	+1
3-6	1	3.4	0	0	−1
4-4	1	3.4	0	0	−1
4-5	0	0	1	3.4	+1
4-6	0	0	0	0	0
4-7	1	3.4	0	0	−1
Total [1]	29	100.0	29	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE S-5. NET CHANGE IN EDUCATIONAL REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

GED level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	10	34.5	2	6.9	−8
2	13	44.8	24	82.8	+11
3	4	13.8	2	6.9	−2
4	2	6.9	1	3.4	−1
Total	29	100.0	29	100.0	0

Compared to the continuing titles, the few new titles do include a disproportionately large number needing average or better mental abilities, clerical perception, and manual dexterity; but the suspect foreman titles, already mentioned, account for all better abilities except for the unusual requirements in manual dexterity required by others (see tables S-7 to S-16).

TABLE S-6. NET CHANGE IN TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	16	52.2	13	44.8	−3
3	3	10.4	11	37.9	+8
4	6	20.7	2	6.9	−4
5	2	6.9	3	10.4	+1
6	1	3.4	0	0	−1
7	1	3.4	0	0	−1
Total	29	100.0	29	100.0	0

A comparison of the past and present aptitudes of the small number of continuing titles with two sets of worker traits shows declines [2] in learning ability, verbal ability, and color discrimination (see tables S-17 to S-26). However, the changes were not large, and most titles already required few of the last two aptitudes. In contrast, there were increases in motor coordination, manual dexterity, finger dexterity, and clerical perception. The first of these involved a sizable net movement; the second and third, moderate net movements; and the last only a small one. There is some ambiguity with respect to changes in spatial comprehension, numerical ability, and form perception, with a seeming net decline in the first, some net increase in the second, and on balance no change in the last. Almost no changes occurred with respect to eye-hand-foot coordination, whose requirements already were low.

Semiskilled titles were more likely to need less learnings and verbal ability and less form perception, but more spatial comprehension and in some cases more motor coordination and dexterity. Unskilled titles were more likely to need more numerical ability, motor coordination, and dexterity but less spatial comprehension. There thus was an equalizing process of sorts. Titles that previously needed at least average mental, but not necessarily physical, abilities now need somewhat more physical and somewhat less mental ability; titles that previously needed below average mental abilities now need more mental and physical abilities.

To summarize, more continuing titles now require average abilities, and fewer call for below average, or in a small number of cases, above average abilities in the physical aptitudes of motor coordination, manual dexterity, and finger dexterity, as well as in clerical perception. In contrast, more titles needed average abilities and fewer below average in one mental aptitude, learning ability, and in one sensory aptitude, color discrimination. The shifts in a second mental aptitude, verbal ability, were complicated but resulted in more titles needing almost no ability. Despite the shift towards great ability in certain physical aptitudes and in clerical perception (and to some extent in numerical ability as well), most titles still require inferior capabilities in all aptitudes except manual dexterity and motor coordination. These two exceptions might have resulted from occupational changes over the last 15 years. If so, the trend has been towards less mental ability and more physical and perceptive abilities, but requirements in the last two cases are still low.

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[2] These are all net, not gross, changes. A small or modest increase or decrease (e.g., "somewhat more") amounts to a net shift equal to at least 6 percent of the total number of titles involved; a moderate increase or decrease to a net shift of 7 to 15 percent; and a large, substantial, or sizable increase or decrease to over 15 percent. The same criteria apply to later discussions of aptitudes.

Nonetheless, the low abilities currently required for most aptitudes suggest little net shift in the skill levels of continuing titles. The changes in continuing titles discussed above involved just a little over one quarter total number, hardly enough to warrant generalizations. New titles did indicate a need for more mental ability, clerical perception, and manual dexterity but chiefly because of a handful of suspect titles. However, the new titles constitute only 10 percent of those in the industry, too few to have a significant effect on overall skill requirements. Nevertheless, both the changes in the continuing and in the new titles point to some increase in both dexterity and clerical perception.

Table S-7. Current Composite Intelligence Requirements (GVN) of Continuing and New Occupational Titles in Slaughtering and Meatpacking by Number of Titles

Composite aptitude ratings[1]	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
222	1	0.9	0	0	1	0.8
333	4	3.7	4	33.3	8	6.7
334	3	2.8	0	0	3	2.5
343	3	2.8	0	0	3	2.5
344	4	3.7	0	0	4	3.4
354	1	.9	1	8.3	2	1.7
355	1	.9	0	0	1	.8
443	2	1.9	0	0	2	1.7
444	43	40.2	3	25.0	46	38.7
445	29	27.1	3	25.0	32	26.9
454	4	3.7	0	0	4	3.4
458	12	11.2	1	8.3	13	10.9
Total[2]	107	100.0	12	100.0	119	100.0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

Table S-8. Current General Learning Ability (G) Requirements of Continuing and New Occupational Titles in Slaughtering and Meatpacking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	1	.9	0	0	1	.9
3	16	15.0	5	41.7	21	17.6
4	90	84.1	7	58.3	97	81.5
5	0	0	0	0	0	0
Total	107	100.0	12	100.0	119	100.0

Table S-9. Current Verbal Ability (V) Requirements of Continuing and New Occupational Titles in Slaughtering and Meatpacking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	1	.9	0	0	1	.9
3	7	6.5	4	33.0	11	9.2
4	81	75.7	6	50.0	87	73.1
5	18	16.8	2	16.7	20	16.8
Total[1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total 100 percent because of rounding.

Table S-10. Current Numerical Ability (N) Requirements of Continuing and New Occupational Titles in Slaughtering and Meatpacking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	1	.9	0	0	1	.9
3	9	8.4	4	33.3	13	10.9
4	55	51.4	4	33.3	59	49.6
5	42	39.3	4	33.3	46	38.6
Total[1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total 100 percent because of rounding.

Table S-11. Current Clerical Perception (Q) Requirements of Continuing and New Occupational Titles in Slaughtering and Meatpacking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	7	6.5	4	33.3	11	9.2
4	36	33.6	2	16.7	38	31.9
5	64	59.8	6	50.0	70	58.8
Total[1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE S-12. CURRENT COORDINATION REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Motor coordination (K)					
1	0	0	0	0	0	0
2	2	1.9	0	0	2	1.7
3	44	41.1	6	50.0	50	42.0
4	60	56.1	4	33.3	64	53.8
5	1	0.9	2	16.7	3	2.5
Total	107	100.0	12	100.0	119	100.0
	b. Eye-hand-foot coordination (E)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	13	12.1	2	16.7	15	12.6
5	94	87.9	10	83.3	104	97.4
Total	107	100.0	12	100.0	119	100.0

TABLE S-13. CURRENT DEXTERITY REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Manual dexterity (M)					
1	0	0	0	0	0	0
2	2	1.9	0	0	2	1.7
3	88	82.2	12	100	100	84.0
4	17	15.9	0	0	17	14.3
5	0	0	0	0	0	0
Total	107	100.0	12	100	119	100.0
	b. Finger dexterity (F)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	23	21.5	2	16.7	25	21.0
4	79	73.8	9	75.0	87	73.1
5	5	4.7	1	8.3	7	5.9
Total	107	100.0	12	100.0	119	100.0

TABLE S-14. CURRENT SPATIAL COMPREHENSION (S) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	1	0.9	0	0	1	0.9
3	11	10.3	1	8.4	12	10.1
4	56	52.3	7	58.3	63	52.9
5	39	36.5	4	33.3	43	36.1
Total	107	100.0	12	100.0	119	100.0

TABLE S-15. CURRENT FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	25	23.4	4	33.3	29	24.4
4	76	71.0	6	50.0	82	68.9
5	6	5.6	2	16.7	8	6.7
Total	107	100.0	12	100.0	119	100.0

TABLE S-16. CURRENT COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	5	4.7	2	16.7	7	5.9
4	22	20.6	2	16.7	24	20.2
5	80	74.7	8	66.7	88	73.9
Total [1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE S-17. NET CHANGES IN COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Composite aptitude ratings [1]	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
222	1	3.4	0	0	−1
333	0	0	1	3.4	+1
334	1	3.4	1	3.4	0
343	0	0	1	3.4	+1
344	7	24.1	2	6.9	−5
345	2	6.9	0	0	−2
354	0	0	1	3.4	+1
444	1	3.4	9	31.0	+8
445	14	48.3	9	31.0	−5
454	0	0	2	6.9	+2
455	3	10.3	3	10.3	0
Total [2]	29	100.0	29	100.0	0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.
[2] Percentages may not total 100 percent because of rounding.

Temperamental Requirements

Relatively few of the titles (about 10 percent) involved varied or discretionary duties (see tables S-27 and S-28). Two-thirds involved repetitive, short-cycle tasks that permit no discretion; another quarter had at least one of these characteristics, although nearly one-fifth in this group did require precision (apparently of a gross sort).

TABLE S-18. NET CHANGE IN GENERAL LEARNING ABILITY (G) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	1	3.4	0	0	-1
3	10	34.5	6	20.7	-4
4	18	62.1	23	79.3	+5
5	0	0	0	0	0
Total	29	100.0	29	100.0	0

TABLE S-19. NET CHANGE IN VERBAL ABILITY (V) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	1	3.4	0	0	-1
3	1	3.4	2	6.9	+1
4	24	82.8	21	72.4	-3
5	3	10.3	6	20.7	+3
Total [1]	29	100.0	29	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE S-20. NET CHANGE IN NUMERICAL ABILITY (N) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	1	3.4	0	0	-1
3	0	0	2	6.9	+2
4	9	31.0	15	51.7	+6
5	19	65.6	12	41.4	-7
Total	29	100.0	29	100.0	0

TABLE S-21. NET CHANGE IN CLERICAL PERCEPTION (Q) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	3	10.3	+3
4	10	34.5	8	27.6	-2
5	19	65.5	18	62.1	-1
Total	29	100.0	29	100.0	0

TABLE S-22. NET CHANGE IN COORDINATION REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Motor coordination (K)				
1	0	0	0	0	0
2	0	0	1	3.4	+1
3	4	13.8	16	55.2	+12
4	25	86.2	12	41.4	-13
5	0	0	0	0	0
Total	29	100.0	29	100.0	0
	b. Eye-hand-foot coordination (E)				
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	6	20.7	7	24.1	+1
5	23	79.3	22	75.9	-1
Total	29	100.0	29	100.0	0

TABLE S-23. NET CHANGE IN DEXTERITY REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Manual dexterity (M)				
1	0	0	0	0	0
2	1	3.4	0	0	-1
3	2	6.9	10	34.5	+8
4	25	86.2	18	62.1	-7
5	1	3.4	1	3.4	0
Total [1]	29	100.0	29	100.0	0
	b. Finger dexterity (F)				
1	0	0	0	0	0
2	0	0	1	3.4	+1
3	14	48.3	21	72.4	+7
4	15	51.7	7	24.2	-8
5	0	0	0	0	0
Total [1]	29	100.0	29	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE S-24. NET CHANGE IN SPATIAL COMPREHENSION (S) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	2	6.9	5	17.2	+3
4	26	89.7	17	58.6	-9
5	1	3.4	7	24.2	+6
Total	29	100.0	29	100.0	0

TABLE S–25. NET CHANGE IN FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	3	10.3	0	0	–3
3	4	13.8	10	34.5	+6
4	21	72.4	18	62.1	–3
5	1	3.4	1	3.4	0
Total[1]	29	100.0	29	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE S–26. NET CHANGE IN COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	6	20.7	2	6.9	–4
4	9	31.0	8	27.6	–1
5	14	48.3	19	65.5	+5
Total	29	100.0	29	100.0	0

Fewer than 20 percent of the titles, for the most part semiskilled, required precision; only 5 percent, evaluation; and fewer than 10 percent required both. In most cases these were exercised within the constraints of a relatively few repetitive tasks and relatively minor decisions. The extent and degree of discretion and precision were small.

Except for the four foreman titles, the new titles showed the same repetitiveness and constraints as the continuing ones (see tables S–27 and S–28). The relatively few titles for which past and present temperaments can be compared indicated net gains in the need for precision, especially by titles with repetitive duties, but a net loss in the number of titles requiring evaluation or evaluation with discretion (see tables S–29 and S–30). Such a mixed picture does not suggest any marked changes in skill requirements, especially in view of the possibility that some of the changes might actually reflect better occupational reporting and analysis.

TABLE S–27. CURRENT TEMPERAMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Repetitiveness and no discretion	[1]63	58.9	6	50.0	69	58.0
Repetitiveness	4	3.7	0	0	4	3.4
No discretion	7	6.5	1	16.7	8	6.7
Repetitiveness, no discretion, and precision	7	6.5	1	16.7	8	6.7
Repetitiveness and precision	8	7.5	0	0	8	6.7
No discretion and precision	2	1.9	0	0	2	1.7
Repetitiveness, no discretion, and evaluation	1	.9	0	0	1	.8
Repetitiveness and evaluation	1	.9	0	0	1	.8
No discretion and evaluation	1	.9	0	0	1	.8
Variation, no discretion, and precision	1	.9	0	0	1	.8
Variation, no discretion, and evaluation	1	.9	0	0	1	.8
Variation and precision	1	.9	0	0	1	.8
Repetitiveness, no discretion, precision, and evaluation	1	.9	0	0	1	.8
Repetitiveness, precision, and evaluation	2	1.9	0	0	2	1.7
Evaluation	1	.9	0	0	1	.8
Evaluation and precision	3	2.8	0	0	3	2.5
Directing, dealing with people, precision, and/or evaluation	[2]3	2.8	[3]4	33.3	7	5.9
Total[4]	117	100.0	12	100.0	119	100.0

[1] Includes one title also involving emergencies.

[2] Includes one title involving evaluation and one involving evaluation and precision.

[3] All also involve evaluation and precision.

[4] Percentages may not total 100 percent because of rounding.

TABLE S–28. CURRENT TEMPERAMENTS OF REPETITIVENESS, VARIATION, NO DISCRETION, PRECISION, AND EVALUATION CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Precision evaluation / Other temperaments	Precision		Evaluation		Precision and evaluation		Neither precision nor evaluation		Total	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Repetitiveness and no discretion	7	9.0	1	1.3	1	1.3	69	88.5	78	100.0
Repetitiveness	8	53.3	1	6.7	2	13.3	4	26.7	15	100.0
No discretion	2	18.1	1	9.1	0	0	8	72.7	11	100.0
Variation and no discretion	2	67.3	1	33.3	0	0	0	0	3	100.0
All others	1	8.3	2	16.7	8	66.7	1	8.3	12	100.0
Total[1]	20	16.8	6	5.0	11	9.2	82	68.9	119	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE S–29. NET CHANGE IN TEMPERAMENTS OF CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Repetitiveness and no discretion	20	69.0	16	55.2	−4
Repetitiveness	0	0	2	6.9	+2
No discretion	0	0	1	3.4	+1
Repetitiveness and precision	1	3.4	4	13.8	+3
No discretion and precision	1	3.4	1	3.4	0
Repetitiveness and evaluation	2	6.9	0	0	−2
Variation, no discretion, and precision	0	0	1	3.4	+1
Variation, no discretion, and evaluation	0	0	1	3.4	+1
Repetitiveness, precision, and evaluation	0	0	2	6.9	+2
Evaluation and precision	4	13.8	1	3.4	−3
Directing and dealing with people	1	3.4	0	0	−1
Total [1]	29	100.0	29	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE S–30. NET CHANGE IN TEMPERAMENTS OF REPETITIVENESS, VARIATION, NO DISCRETION, PRECISION, AND EVALUATION, CONTINUING OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Precision and evaluation / Other temperaments	Precision	Evaluation	Precision and evaluation	Neither precision nor evaluation	Total net changes
Repetitiveness and no discretion	0	0	0	−4	−4
Repetitiveness	+3	−2	+2	+2	+5
No discretion	0	0	0	+1	+1
Variations and no discretion	+1	+1	0	0	+2
All others	0	0	−3	−1	−4
Total	+4	−1	−1	−2	0

TABLE S–31. WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN SLAUGHTERING AND MEATPACKING BY NUMBER OF TITLES

Worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Primarily involving things:						
Handling	51	47.7	4	33.3	55	46.2
Feeding-offbearing	3	2.8	0	0	3	2.5
Tending	28	26.2	2	16.7	30	25.2
Manipulating	8	7.5	1	8.3	9	7.6
Operating-controlling	2	1.9	0	0	2	1.7
Primarily involving things and data:						
Handling and comparing	4	3.7	0	0	4	3.4
Handling and copying	1	.9	0	0	1	.8
Handling and compiling	4	3.7	0	0	4	
Manipulating and comparing	1	.9	0	0	1	3.4 .8
Precision working and compiling	2	1.9	1	8.3	3	2.5
Primarily involving data and people:						
Coordinating and supervising	2	1.9	0	0	2	1.7
Involving things, data, and people:						
Precision working, coordinating, and supervising	1	.9	1	8.3	2	1.7
Setting up, coordinating, and supervising	0	0	3	25.0	3	2.5
Total [1]	107	100.0	12	100.0	119	100.0

[1] Percentages may not total to 100 percent because of rounding.

Worker Functions

Three-quarters of the continuing titles are low-skilled handling or machine-tending in nature, and so is the bulk of the new titles except for the new foreman titles (see table S–31). This pattern of worker functions substantiates earlier findings that most titles are repetitive, unskilled, or semiskilled, requiring limited discretion, and that changes in skill requirements on balance have been negligible.

Changes in Occupational Content

No more than 17 (16 percent) of the 107 continuing titles appear to have undergone meaningful changes in content other than what can be attributed to better or more detailed descriptions of duties and responsibilities previously covered. Eleven of these 17 involved changes in equipment or methods that seemed to leave skill requirements unchanged, even though manual duties or manual parts of an operation were often replaced. Changes in equipment were more frequent than changes in processes (seven of the former compared to four of the latter) and involved the introduction of faster or safer machinery. The four titles with changes in methods included two, both nearly obsolete, that suffered reductions in duties and manning. The other two acquired additional duties requiring the same basic skills as already needed. One of these also involved a cut in manning.

All or nearly all of these 11 titles with unchanged skill levels currently require little education (no more than the second level), little training (no more than a month), and below average aptitudinal abilities, except with respect to manual dexterity and in some cases motor coordination. Eight of the 11 involve repetitive, short-cycle tasks with no room for discretion. Nine of the 11 were classified as unskilled in the second edition of the D.O.T. Only 3 of the 11 require precision.

The remaining 6 of the 17 titles with meaningful changes in content are evenly divided between those which experienced skill decreases and increases. The current characteristics of the 3 titles with skill decreases are much the same as those of the 11 with unchanged skill levels and have similar aptitudinal and temperamental requirements, with 2 exceptions. Two of the 3 require average amounts of motor coordination and finger dexterity; in contrast, only 4 of the 11 without skill changes require as much motor coordination, and only 2 as much finger dexterity. Job simplification accounted for the decline in skill of one of the three whose skill levels fell. New equipment that assumed work formerly done manually or that require less worker judgment accounted for the other two. (One of these also involved reduced manning.)

The three titles whose skill levels rose seemed to require somewhat higher levels of intelligence and perhaps more motor coordination than others. Two of them need average amounts of learning ability and motor coordination, and one of these two also needs average amounts of verbal ability and numerical ability. Nonetheless, two of the three involve repetitive work requiring no discretion and limited education (second level) and training (only a short demonstration). The third, a supervisory title, requires above average amounts of education and training and is the only one that needs average learning and verbal and numerical abilities. A change in methods resulted in this title having more responsibilities. New equipment that increased the number of operations accounted for the occupational content changes of the other two.

Changes in content may possibly have led to the somewhat better showing of the three titles whose skill levels increased with respect to intelligence but probably not to educational or training requirements. Few of the titles with no meaningful changes in content and for which there are two sets of worker traits had similar increases in intelligence requirements or needed as much learning ability. On the other hand, many had increases in educational requirements and somewhat fewer in training requirements, although admittedly to levels that were still low (level 2 in educational development and from over 1 to 3 months in vocational preparation).

Changes in content do not seem associated with major changes in skill requirements. Only six titles apparently had changes in content that involved changes in skill levels, and these were balanced off with three increases and three decreases. In most cases, accompanying changes in aptitudes, temperaments, education, and training showed no consistent patterns. However, the few changes in content that did lead to skill increases seemed to result in increases in required amounts of mental abilities, although to levels no better than average.

Conclusions

It is doubtful that there have been any overall changes in skill level in slaughtering and meatpacking. Educational requirements have increased but training requirements have decreased, while a majority of the titles still need very little of either. Changes have occurred in the aptitudinal abilities needed by continuing titles; further, differences between the requirements of new and continuing titles do exist. However, the currently low abilities needed in most aptitudes indicate that little change has taken place. The generally low-skill worker functions of most of the titles, their limited temperamental needs, and the limited changes in these suggest the same story. Finally, meaningful changes in occupational content have been few and the resulting changes in skill levels even fewer.

Rubber Tires and Tubes

Educational and Vocational Requirements

Past and present worker traits exist for 11 out of the 53 continuing occupational titles in this industry. There was a net increase in the educational requirements of these 11, which was more than offset by a net drop in the training requirements (see tables R–1 to R–3). Educational requirements of the 11 formerly were concentrated at the lowest levels, 1 and 2; now nearly half are at level 3. Nearly half of the 11 titles formerly needed anywhere from over 6 months to 2 years' vocational preparation; now, however, about half need only 3 months or less.[1]

The increases in educational needs occurred chiefly among titles with low requirements to start. The drop in training needs, however, occurred chiefly among those with high requirements to start. Overall, there was a modest leveling process that reduced the number of titles with high educational and low training requirements. There was a tendency for titles that originally required little education or training to need somewhat more of both. Titles that originally required almost no education but moderate amounts of training seemed to require at least some high school and considerably more training.

Nevertheless, the bulk of the blue-collar titles still require relatively little educational and vocational training, indicating that no significant skill increases have occurred (see tables R–4 to R–6). Present educational needs of 75 percent of the 77 current titles are no higher than level 2, and present training requirements of 56 percent, no more than 30 days. Moreover, the 24 new titles require even less education and training than the continuing ones. Nearly 90 percent of the new titles need no more than a level 2 education, compared to 70 percent of the continuing titles; and over four-fifths of the new titles need no more than 3 months training compared to three-quarters of the continuing titles.

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[1] Five titles had increases in educational requirements; two had decreases; and four had no changes. In contrast, one title had an increase in training requirements; five had decreases and five had no changes.

Of course, only very guarded conclusions are warranted with respect to changes in educational and training requirements of continuing titles, because two sets of data exist for so few of the continuing titles. The net increase in their educational requirements, for example, is not substantiated by changes in occupational content or in aptitudinal ratings. Compared to the continuing titles, the new ones include a disproportionately high number requiring limited education and, to a smaller extent, limited training.

TABLE R–1. NET CHANGE IN EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

GED–SVP levels	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1–2	3	27.3	2	18.2	−1
2–1	1	9.1	0	0	−1
2–2	0	0	2	18.2	+2
2–3	0	0	2	18.2	+2
2–4	1	9.1	0	0	−1
2–5	0	0	0	0	0
2–6	3	27.3	0	0	−3
3–4	1	9.1	2	18.2	+1
3–5	0	0	2	18.2	+2
3–6	1	9.1	1	9.1	0
4–6	1	9.1	0	0	−1
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–2. NET CHANGE IN EDUCATIONAL REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

GED level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	3	27.3	2	18.2	−1
2	5	45.5	4	36.4	−1
3	2	18.2	5	45.5	+3
4	1	9.1	0	0	−1
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–3. NET CHANGE IN TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	9.1	0	0	−1
2	3	27.3	4	36.4	+1
3	0	0	2	18.2	+2
4	2	18.2	2	18.2	0
5	0	0	2	18.2	+2
6	5	45.5	1	9.1	−4
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–4. CURRENT EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

GED–SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1–1	3	5.7	1	4.2	4	5.2
1–2	11	20.7	3	12.5	14	18.2
2–1	0	0	0	0	0	0
2–2	15	28.3	9	37.5	24	31.2
2–3	8	15.1	7	29.2	15	19.5
2–4	0	0	1	4.2	1	1.3
3–2	1	1.9	0	0	1	1.3
3–3	2	3.8	0	0	2	2.6
3–4	5	9.4	0	0	5	6.5
3–5	5	9.4	1	4.2	6	7.8
3–6	2	3.8	1	4.2	3	3.9
4–6	1	1.9	1	4.2	2	2.6
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–5. CURRENT EDUCATIONAL REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

GED level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	14	26.4	4	16.7	18	23.4
2	23	43.4	17	70.8	40	51.9
3	15	28.3	2	8.3	17	22.1
4	1	1.9	1	4.2	2	2.6
Total	53	100.0	24	100.0	77	100.0

TABLE R–6. CURRENT TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

SVP levels	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	3	5.7	1	4.2	4	5.2
2	27	50.9	12	50.0	39	50.6
3	10	18.9	7	29.1	17	22.1
4	5	9.4	1	4.2	6	7.8
5	5	9.4	1	4.2	6	7.8
6	3	5.7	2	8.3	5	6.5
Total	53	100.0	24	100.0	77	100.0

Aptitudinal Requirements

The present aptitudinal requirements of a large proportion of the current occupational titles are low, except in manual dexterity and, to some extent, motor coordination (see tables R–7 to R–16). A majority of the titles need only below average abilities in the three intelligence aptitudes, clerical perception, finger dexterity, form perception, spatial comprehension, eye-hand-foot coordination, and color discrimination. The amount of ability needed is unexceptional (typically only average), even with respect to manual dexterity and motor coordination.

In comparison, relatively more of the new titles than continuing ones seem to need even less learning ability, clerical perception, spatial comprehension, and form perception. On the other hand, a larger proportion of the new titles need average, and a smaller proportion below average, manual and finger dexterity. Nevertheless, a majority of titles still need below average amounts of finger dexterity. Larger proportions of the new titles also need more motor coordination and color discrimination. However, in the case of motor coordination the change is small, and color discrimination still leaves most titles with inferior ratings. There is little difference between new and continuing titles with respect to verbal and numerical abilities and eye-hand-foot coordination.

The aptitudes needed by the few continuing titles for which there are two sets of worker traits indicate somewhat different trends than new titles (see tables R-17 to R-26). More continuing titles now need average instead of below average verbal and numerical aptitudes, manual dexterity, and both kinds of coordination. More continuing titles also need more clerical perception now, but still less than average amounts, while fewer need average learning ability and form perception. There is no difference or little with respect to finger dexterity and color discrimination, and there are mixed trends with respect to spatial comprehension.

In contrast, relatively more new titles than continuing ones need a lower rating of clerical perception and spatial comprehension and a higher rating of finger dexterity. However, differences resulting from the comparison of continuing titles and the comparison of new with continuing titles are relatively minor and probably are explained by the small number of continuing titles for which former worker traits are available. Nevertheless, the extent to which more continuing titles require less ability in various aptitudes may understate the true situation because so large a percentage of titles had such limited requirements to start.

Overall, then, new titles tend to need less intelligence but more manual and finger dexterity and perhaps coordination. To some extent the change in continuing titles shows a similar pattern. However, most titles continue to need comparatively low capacities with respect to all aptitudes except manual dexterity. What occupational changes may have occurred seem to have had surprisingly little effect as a whole on aptitudes.

TABLE R-7. CURRENT COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Composite aptitude ratings [1]	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
333	1	1.9	2	8.3	3	3.9
334	10	18.9	1	4.2	11	14.3
343	1	1.9	0	0	1	1.3
344	3	5.7	0	0	3	3.9
444	20	37.7	13	54.2	33	42.9
445	11	20.8	3	12.5	14	18.2
455	7	13.2	5	20.8	12	15.6
Total [2]	53	100.0	24	100.0	77	100.0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.
[2] Percentages may not total 100 percent because of rounding.

TABLE R-8. CURRENT GENERAL LEARNING ABILITY (G) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	15	28.3	3	12.5	18	23.4
4	38	71.7	21	87.5	59	76.6
5	0	0	0	0	0	0
Total	53	100.0	24	100.0	77	100.0

TABLE R-9. CURRENT VERBAL ABILITY (V) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	11	20.8	3	12.5	14	18.2
4	35	66.0	16	66.7	51	66.2
5	7	13.2	5	20.8	12	15.6
Total	53	100.0	24	100.0	77	100.0

TABLE R-10. CURRENT NUMERICAL ABILITY (N) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	2	3.8	2	8.3	4	5.2
4	33	62.3	14	58.3	47	61.0
5	18	34.0	8	33.3	26	33.8
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE R-11. CURRENT CLERICAL PERCEPTION (Q) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	2	3.8	1	4.2	3	3.9
4	29	54.7	17	70.8	46	59.7
5	22	41.5	6	25.0	28	36.4
Total	53	100.0	24	100.0	77	100.0

TABLE R-12. CURRENT COORDINATION REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Motor coordination (K)					
1	0	0	0	0	0	0
2	0	0	1	4.2	1	1.3
3	29	54.7	15	62.5	44	57.1
4	24	45.3	8	33.3	32	41.6
5	0	0	0	0	0	0
Total	53	100.0	24	100.0	77	100.0
	b. Eye-hand-foot coordination (E)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	1	1.9	1	4.1	2	2.6
4	17	32.1	7	29.2	24	31.2
5	35	66.0	16	66.7	51	66.2
Total	53	100.0	24	100.0	77	100.0

TABLE R-13. CURRENT DEXTERITY REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Manual dexterity (M)					
1	0	0	0	0	0	0
2	0	0	1	4.2	1	1.3
3	40	75.5	20	83.3	60	77.9
4	13	24.5	3	12.5	16	20.8
5	0	0	0	0	0	0
Total	53	100.0	24	100.0	77	100.0
	b. Finger dexterity (F)					
1	0	0	0	0	0	0
2	0	0	1	4.2	1	1.3
3	11	20.8	8	33.3	19	24.7
4	38	71.7	13	54.2	51	66.2
5	4	7.5	2	8.3	6	7.8
Total	53	100.0	24	100.0	77	100.0

TABLE R-14. CURRENT SPATIAL COMPREHENSION (S) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	11	20.7	2	8.3	13	16.8
4	23	43.4	17	70.8	40	51.9
5	19	35.9	5	20.8	24	31.2
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE R-15. CURRENT FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	2	3.8	2	8.3	4	5.2
3	22	41.5	4	16.7	26	33.8
4	19	35.8	16	66.7	35	45.5
5	10	18.9	2	8.3	12	15.6
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE R-16. CURRENT COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	7	13.2	5	20.8	12	15.6
5	46	86.8	19	79.2	65	84.4
Total	53	100.0	24	100.0	77	100.0

TABLE R-17. NET CHANGE IN COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Composite aptitude ratings [1]	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
333	1	9.1	5	45.5	+4
334	2	18.2	0	0	−2
344	3	27.3	0	0	−3
345	1	9.1	0	0	−1
444	0	0	3	27.3	+3
445	3	27.3	2	18.2	−1
455	1	9.1	1	9.1	0
Total [2]	11	100.0	11	100.0	0

[1] The first number is the general learning ability (G) rating; the second verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

TABLE R-18. NET CHANGE IN GENERAL LEARNING ABILITY (G) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	7	63.6	5	45.5	−2
4	4	36.4	6	54.5	+2
5	0	0	0	0	0
Total	11	100.0	11	100.0	0

TABLE R-19. NET CHANGE IN VERBAL ABILITY (V) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	3	27.3	5	45.5	+2
4	7	63.6	5	45.5	−2
5	1	9.1	1	9.1	0
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE R-20. NET CHANGE IN NUMERICAL ABILITY (N) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	1	9.1	0	0	−1
4	5	45.5	8	72.7	+3
5	5	45.5	3	27.3	−2
Total	11	100.0	11	100.0	0

TABLE R-21. NET CHANGE IN CLERICAL PERCEPTION (Q) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	4	36.4	7	63.6	+3
5	7	63.6	4	36.4	−3
Total	11	100.0	11	100.0	0

TABLE R-22. NET CHANGE IN COORDINATION REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Motor coordination (K)				
1	0	0	0	0	0
2	0	0	0	0	0
3	4	36.4	8	72.7	+4
4	7	63.6	3	27.3	−4
5	0	0	0	0	0
Total	11	100.0	11	100.0	0
	b. Eye-hand-foot coordination (E)				
1	0	0	0	0	0
2	0	0	0	0	0
3	3	27.3	6	54.5	+3
4	8	72.7	5	45.5	−3
5	0	0	0	0	0
Total	11	100.0	11	100.0	0

TABLE R-23. NET CHANGE IN DEXTERITY REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Manual dexterity (M)				
1	0	0	0	0	0
2	0	0	0	0	0
3	8	72.7	11	100.0	+3
4	3	27.3	0	0	−3
5	0	0	0	0	0
Total	11	100.0	11	100.0	0
	b. Finger dexterity (F)				
	0	0	0	0	0
2	0	0	0	0	0
3	4	36.4	4	36.4	0
4	7	63.6	7	63.6	0
5	0	0	0	0	0
Total	11	100.0	11	100.0	0

TABLE R-24. NET CHANGE IN SPATIAL COMPENSATION (S) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	3	27.3	4	36.4	+1
4	7	63.6	4	36.4	−3
5	1	9.1	3	27.3	+2
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–25. NET CHANGE IN FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	7	63.6	6	54.5	−1
4	4	36.4	3	27.3	−1
5	0	0	2	18.2	+2
Total	11	100.0	11	100.0	0

TABLE R–26. NET CHANGE IN COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	3	27.3	2	18.2	−1
4	8	72.7	9	81.8	+1
5	0	0	0	0	0
Total	11	100.0	11	100.0	0

Temperamental Requirements

The predominant characteristic of more than two-thirds of the titles is their repetitive, short cycle natures (see table R–27). Further, over half the titles involve no discretion or variety. However, nearly two-fifths require precision, of which only a third are repetitive as well; and a quarter require both evaluation and precision, although two-thirds of these also are repetitive.

Thus there seem to be three categories of titles: (1) Comparatively simple ones involving little variation or discretion; (2) a relatively smaller number requiring evaluation, precision or both, but still repetitive; and (3) even fewer, no more than 6 or 7 percent, requiring evaluation, precision or both, and involving variety and discretion as well. Repetitive, short-cycle titles that also involve precision and evaluation are relatively more numerous, constituting about a third.

The temperaments of the new do not differ from those of the continuing titles, except that new titles requiring evaluation and precision are less likely to be repetitive and short cycle and more likely to encompass varied duties. To that extent, they may point to increases in skill levels over time.

The comparison of the past and present temperaments of the 11 continuing titles with both sets of data shows fewer titles involving only evaluation and precision and more involving repetitive duties or no discretion (see table R–28). The temperaments of 6 of the 11 changed. Two that originally required evaluation and precision apparently were downgraded. One became repetitive and devoid of discretion; the other retained its evaluation and precision but became repetitive. However, three of the original four repetitive titles allowing no discretion apparently were upgraded. Two no longer are repetitive; the third no longer lacks discretion. However, these findings should be treated cautiously, for there are no changes in the content of the occupational descriptions to warrant these revised temperaments. Perhaps they simply reflect better occupational analysis.

Taken together, the comparison of the new with the continuing titles and the comparison of the former and current temperaments of the few continuing titles make it difficult to say that there has been any change in skill levels.

TABLE R–27. CURRENT TEMPERAMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Repetitiveness and no discretion	13	24.5	6	25	19	24.7
Repetitiveness	13	24.5	6	25	19	24.7
No discretion	4	7.5	0	0	4	5.2
Repetitiveness and precision	7	13.2	3	12.5	10	13
Repetitiveness and evaluation	3	5.7	1	4.2	4	5.2
Variation and evaluation	0	0	1	4.2	1	1.3
Repetitiveness, evaluation, and precision	8	15.1	4	16.7	12	15.6
Evaluation and precision	4	7.5	3	12.5	7	9.1
Directing, dealing with people, evaluation, and precision	1	1.9	0	0	1	1.3
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE R–28. NET CHANGE IN TEMPERAMENTS OF CONTINUING OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Repetitiveness and no discretion	4	36.4	2	18.2	−2
Repetitiveness	0	0	1	9.1	+1
No discretion	0	0	2	18.2	+2
Repetitiveness and precision	1	9.1	1	9.1	0
Repetitiveness, evaluation, and precision	0	0	1	9.1	+1
Evaluation and precision	6	54.5	4	36.4	−2
Total [1]	11	100.0	11	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Worker Functions

Over half the continuing occupational titles are low-skilled handling, feeding-offbearing, and tending titles, and another 40 percent are medium-skilled manipulating and operating-controlling (see table R-29). The new titles are not much different in their overall degree of complexity than the continuing ones. The chief differences are that the new titles include a larger proportion of occupations at the bottom level of handling, at the low skilled level of tending, and at the intermediate level of manipulating, and a smaller proportion at the intermediate level of operating-controlling. The basic similarity between the worker functions of the new and continuing titles is another indication that on balance skill levels probably have not changed much and certainly have not risen.

TABLE R-29. WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN RUBBER TIRES AND TUBES BY NUMBER OF TITLES

Worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Handling	7	13.2	5	20.8	12	15.6
Handling and comparing	3	5.7	0	0	3	3.9
Feeding-offbearing	7	13.2	1	4.2	8	10.4
Tending	12	22.6	8	33.3	20	26.0
Manipulating	7	13.2	7	29.7	14	18.2
Manipulating and compiling	4	7.5	1	4.2	5	6.5
Operating-controlling	10	18.9	0	0	10	13.0
Precision working	1	1.9	2	8.3	3	3.9
Precision working and compiling	1	1.9	0	0	1	1.3
Setting up, coordinating, and supervising	1	1.9	0	0	1	1.3
Total [1]	53	100.0	24	100.0	77	100.0

[1] Percentages may not total 100 percent because of rounding.

Changes in Occupational Content

The descriptions of about a third of the 53 continuing titles showed changes, but most of the changed descriptions (15) involved either no apparent change in skill level (9) or a decrease (6). Of the 18 titles showing description changes, 13 and possibly 14 now require little education or training, and 4 others require only moderate amounts. These proportions correspond roughly to those of all the titles in rubber tires and tubes.

Increases in skills generally occurred when tasks or duties were added that seemed to require more manual ability, knowledge, responsibility, education, or training than those existing. Decreases in skill usually occurred when tasks were eliminated or so changed that less manual ability, knowledge, responsibility, education, or training seemed needed. A change in occupational content or description with no change in skill typically added duties that required the same amount of skill as those already part of the title.

The majority of the description changes (involving 12 titles) resulted from changes in equipment that took over duties formerly done by a worker or that required less worker judgment. They were not the result of changes in work methods that altered the number of tasks or responsibilities independently of changes in equipment or machinery.

Only three titles had skill increases. The increases of two of these seemed to result from more complicated equipment that transformed comparatively simple manual operations into ones in which the worker had to adjust equipment or which required more precision.

Fifty-five percent of the titles with changes in descriptions but not in skill level seemed to involve faster or safer equipment or both. The others involved added duties that seemed to demand the same amount of skill as duties already assigned.

Only seven titles became obsolete: Three involved unskilled manual labor; another three, comparatively simple machine tending or manipulating; the seventh involved directing the loading and unloading of curing ovens. All were eliminated by a new way of extruding and curing rubber tubes. Two other titles appear to be almost obsolete. One originally needed a comparatively high degree of education and training (level 4 of educational development and from over a year to 2 years vocational preparation), but had undergone a change in technology that dramatically cut both. The other title currently needs little education or training but apparently had an increase in skill if changes in its description represent actual changes rather than better occupational analysis.

Skill levels fell for titles which chiefly now (1) have low requirements in all aptitudes except manual dexterity and motor coordination; (2) need limited amounts of education and training; and (3) involve repetitive, short-cycle, machine-tending, or machine-feeding tasks of limited discretion. Changes in occupational content may have adversely affected these worker traits and functions with the exception of manual dexterity and both types of coordination. The need for manual dexterity and motor coordination rose for two of the three titles with two sets of worker trait data, while the need for eye-hand-foot coordination rose for all three. On the other hand, education requirements, training requirements, or both fell for two of the three. Our limited data indicate that other aptitudes, including intelligence, were not affected. Titles whose skills seemed to fall were not at the top of the skill hierarchy but near the bottom, and the changes in content probably reduced the amount of education and training needed at the same time that the required amount of dexterity and coordination was raised.

Although it is hazardous to generalize from just three titles, those whose skills rose also seemed to need little education or training; limited learning, verbal, or numerical ability; and limited amounts of other abilities except manual dexterity, motor coordination, and form perception. However, titles with skill increases have a somewhat higher level of complexity than those whose skills fell, and while repetitive did not necessarily restrict discretion. Although there is no way to tell whether or not these worker traits and worker functions are the results of changes in content and description, these changes apparently have not led to exceptional educational, training, or mental requirements, and have not modified the repetitive nature of the work. Again, the changes seem to be in the direction of requiring more dexterity and coordination rather than learning ability or other mental aptitudes.

Equipment changes that have affected skill levels in both directions seem to demand less form perception but more motor coordination and dexterity, both manual and finger, to ensure proper tending of machines and to prevent breakdowns. However, the level of such aptitudes, while higher, is no better than average.

Although there are few titles on which to base conclusions, our analysis suggests that technological changes probably have not contributed to the net increase in the educational requirements for the continuing titles with two sets of worker traits. Perhaps the reason for this increase is improved occupational analysis; perhaps it is a reflection of a general increase in educational requirements independent of any explicit change in work content or its requirements. Regardless, the overall level of education and training required by titles in the industry remains low.

Most of the titles that experienced content changes not leading to changes in skill levels now involve repetitive, machine-tending or feeding tasks but not necessarily limits on discretion. They now need limited education and training (six of the nine); limited learning, verbal or numerical abilities (seven of the nine); and limited abilities in other aptitudes, except manual dexterity, finger dexterity, and possibly motor coordination. Even these, however, generally need only average capabilities. Of the nine titles involved, seven require average manual dexterity; five, average finger dexterity; and four, average motor coordination.

Conclusions

There is little evidence of a significant net change in skill levels. There was some increase in educational requirements and a net drop in training requirements, but the increase probably does not signify a change in skill level. Less learning and other mental abilities but more dexterity and coordination are needed. However, levels of dexterity and coordination are still not exceptional; moreover, little overall change in aptitudinal requirements has occurred. Similarly, the temperaments required of the titles and their level of complexity suggest no change in skills on balance. Changes in occupational content have occurred; they have involved both increases and decreases in skill levels; and they indicate some net decline in skill levels. However, only about a third of the titles had any change in content, and fewer than half of these had any change in skill levels.

Machine Shop Trades

Educational and Training Requirements

Slightly over half the current titles now require a fourth level educational preparation, that is, at least a high school diploma (see tables MA–1 and MA–2). Nearly all the rest need less education, with the major share of these at level 3 (at least some high school). Taken together, the third and fourth levels account for almost 90 percent of all the titles. Another way of looking at educational requirements is that about half the titles need only modest amounts of education (some high school or none at all), and half need a moderate amount (high school or the equivalent).

Most of the titles (157[1] of 170) are either skilled or semiskilled, with nearly as many of the former as the latter. Over 85 percent of the skilled titles now require a fourth level of educational preparation; 60 percent of the semiskilled require a third level; but another 22 percent, just a second level. Most of the few (eight in all) unskilled titles need only a second level. Thus, it is primarily the skilled titles that need at least a high school education.

There is considerably more variation in training than educational requirements (see tables MA–1 and MA–3). There is some clustering at 2 to 4 years'[2] training (29 percent) and some at 6 months or less (26 percent).[3] However, it is difficult to generalize further about the amounts of vocational training needed because of the dispersion of titles at each level of vocational preparation. Although over half the titles need at least 1 year of training, of these more than half need 2 to 4 years. The remaining titles (46 percent) need no more than 12 months, with most of these (nearly three-fifths) requiring 6 months or less.

This variation in training requirements is true of each skill group. Although a majority (60 percent) of the skilled titles need 2 to 4 years' training, nearly one-quarter (23 percent) need only 6 to 12 months and 1 to 2 years, and somewhat under one-fifth (17 percent), 4 to 10 years. Semiskilled titles show the most dispersion. Thirty-one percent require no more than 3 months; 17 percent, 3 to 6 months; 34 percent, 6 to 12 months; and 20 percent, 1 to 4 years. Five required at least 2 years, but all but one were apprentices.

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[1] Included are three supervisory titles which the second edition of the D.O.T. classifies as skilled craftsmen.

[2] Understood to exclude the first figure in the interval and to include the second.

[3] Alternatively, if aggregated further, there is a clustering at 6 months or less (26 percent) or over 2 years (40 percent).

A comparison of the past and present educational requirements of the 77 titles with two sets of worker traits shows a moderate net increase in educational requirements but a greater net increase in training requirements (see tables MA–4 to MA–6). The net number of continuing titles needing a fourth level of education rose by nearly one-quarter, while the number needing no more than a third level fell by a tenth. However, all net shifts amounted to less than 10 percent of the 77 continuing titles.

Still, very few continuing titles even now require more than a fourth level of education, and these are chiefly the skilled (see tables MA–4 and MA–5). Nearly half the continuing titles now are at level 4 and most of the rest at levels 2 and 3. Previously, nearly three-fifths (58 percent) were at the second and third levels with nearly two-fifths (38 percent) at the fourth. At both times, however, a majority of titles (78 percent previously and 83 percent now) were at the third and fourth levels. The main change has been an upward shift within this group, so that relatively fewer titles now are at the third level (40 percent before, compared to 36 percent now) and relatively more are at the fourth level (38 percent before, compared to 47 now).

Most of the titles with increases in education were skilled or semiskilled [4] and formerly needed a second or third level of education. Thus, of continuing titles with two sets of worker traits, skilled were 39 percent and semiskilled 48 percent, where originally 35 percent required a second-level education and 57 percent required a third level. However, skilled titles were underrepresented and unskilled overrepresented where educational requirements rose. Skilled titles, formerly 45 percent of the continuing titles, were only 39 percent of those needing more education. The respective proportions for unskilled titles were 5 and 9 percent. The proportion of semiskilled titles was about the same in both cases (47 percent of the titles and 48 percent of those with increases in education). In addition, professional titles were 2 percent of the continuing titles with two sets of worker traits but 4 percent of those needing more education.

The increase in training requirements was substantial, and the pattern was more complicated than in educational requirements (see tables MA–4 to MA–6). There was a large net increase of 100 percent in the number of titles requiring 2 to 4 years; a moderate net increase of 19 percent requiring anywhere up to 6 months, accompanied by net decreases; 27 percent and 50 percent, respectively, requiring 4 to 10 years at the top, and in the middle, requiring anywhere from 6 months to 2 years. The net result was some polarization.

Formerly, titles were more evenly distributed from 1 to 3 months up to 4 to 10 years, although relatively more required 6 to 12 months than any other period of preparation. The training requirements of a few titles at the very top (4 to 10 years) fell, while those at lower levels anywhere from 3 months up to 2 years both fell and rose (see tables MA–4 and MA–6). Increases in training were more likely to occur among skilled titles, decreases among semiskilled and unskilled. For example, skilled titles constituted about 45 percent of the continuing titles, but 63 percent of those needing more vocational preparation; semiskilled titles constituted 47 percent of the continuing titles, but 58 percent of those needing less training. The respective proportions for unskilled titles were 5 and 8 percent.

Net increases in training also occurred among continuing titles requiring very little preparation (up to 3 months) or moderate amounts (1 to 2 years), and net decreases occurred among those requiring modest amounts of preparation (3 to 6 months) or a great deal (4 to 10 years). For example, titles with training needs of up to 3 months were 20 percent of all titles, but 30 percent of those whose training requirements rose; titles with training requirements of 1 to 2 years were 13 percent of all titles but 26 percent of those whose training requirements rose. In contrast, titles originally needing 3 to 6 months' and 4 to 10 years' preparation were each 14 percent of the continuing titles, but 27 percent and 23 percent, respectively, of those with a drop in training requirements.

In general, titles that already required fairly long periods of preparation were likely to require even longer periods, unless already at the top, and those that required relatively short periods of preparation were likely not to require either longer periods or shorter ones.

The number of new titles (57) was relatively large, accounting for one-third of all the current and at least half the continuing titles. Few of the new titles were repetitive or limited worker discretion. Four-fifths (45 of the 57) required precision and use of judgment. Only 12 were repetitive, or both repetitive and lacking in discretion. About half involved the operation of specialized machine tools and over two-fifths setting up as well. Twenty-one (37 percent) of the 57 new titles were skilled: [5] 6 tool and die makers, 5 machinists, and 10 specialized tool operators and setup men.

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[4] According to the classification of the second edition of the D.O.T.

[5] Using classifications of the second edition of the D.O.T.

However, the proportion of skilled titles among the new was somewhat less than among the continuing titles. Four of the new titles resulted from recent technology. Three involved the operation of tape-controlled tools, and the fourth, ultrasonic machining. However, two of the former required little education or training (less than high school and no more than 3 months' training); the third required almost as little (some high school and 6 to 12 months' training).

On the average, the new titles required less education and had a different training pattern than the continuing titles. A considerably larger proportion of the new titles than the continuing needed only a third level of education, and a smaller proportion, a fourth level or higher. Substantially fewer of the new titles, relatively, needed a great deal of training (either 2 to 4 years or 4 to 10) or comparatively little (6 months or less), but many more, relatively, required intermediate amounts (6 to 12 months or 1 to 2 years). New titles, in short, showed more clustering at moderate levels of preparation. Their training requirements were neither very short nor very long.

To summarize, the educational and training requirements of continuing titles with two sets of worker traits tended to rise. Titles needing long training periods now need longer ones, and titles needing short periods now need the same as before or shorter. On the other hand, the educational needs of the many new titles tended to be lower, and their vocational requirements were neither as long nor as short as those of many of the continuing titles. The few titles based on new techniques needed comparatively little education or training. In view of the large number of new titles and changing technology, the future may be one in which machine shop skill requirements do not rise and perhaps decline somewhat, but the overall level remains relatively high.

TABLE MA-1. CURRENT EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

GED-SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1-1	0	0	1	1.8	1	0.6
2-2	5	4.4	2	3.5	7	4.1
2-3	9	8.0	5	8.8	14	8.2
2-4	2	1.8	0	0	2	1.2
3-2	0	0	1	1.8	1	.6
3-3	7	6.2	1	1.8	8	4.7
3-4	10	8.8	1	1.8	11	6.5
3-5	14	12.4	16	28.1	30	17.6
3-6	4	3.5	6	10.5	10	5.9
3-7	0	0	1	1.8	1	.6
4-4	1	.9	0	0	1	.6
4-5	1	.9	2	3.5	3	1.8
4-6	9	8.0	4	7.0	13	7.7
4-7	37	32.7	12	21.0	49	28.8
4-8	9	8.0	4	7.0	13	7.7
5-6	0	0	1	1.8	1	.6
5-7	0	0	0	0	0	.0
5-8	4	3.5	0	0	4	2.4
6-8	1	.9	0	0	1	.6
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA-2. CURRENT EDUCATIONAL REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

GED level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	1	1.8	1	0.6
2	16	14.2	7	12.3	23	13.5
3	35	31.0	26	45.6	61	35.9
4	57	50.4	22	38.6	79	46.5
5	4	3.5	1	1.8	5	2.9
6	1	.9	0	0	1	.6
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA-3. CURRENT TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES ON MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	1	1.8	1	0.6
2	5	4.4	3	5.3	8	4.7
3	16	14.2	6	10.5	22	12.9
4	13	11.5	1	1.8	14	8.2
5	15	13.3	18	31.6	33	19.4
6	13	11.5	11	19.3	24	14.1
7	37	32.7	13	22.8	50	29.4
8	14	12.4	4	7.0	18	10.6
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA-4. NET CHANGE IN EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

GED-SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1-3	1	1.3	0	0	−1
2-2	2	2.6	4	5.2	+2
2-3	9	11.7	5	6.5	−4
2-4	3	3.9	1	1.3	−2
3-3	1	1.3	7	9.1	+6
3-4	8	10.4	13	16.9	+5
3-5	17	22.1	6	7.8	−11
3-6	3	3.9	2	2.6	−1
3-7	2	2.6	0	0	−2
4-3	2	2.6	0	0	−2
4-4	0	0	1	1.3	+1
4-5	1	1.3	1	1.3	0
4-6	7	9.1	5	6.5	−2
4-7	10	13.0	24	31.2	+14
4-8	9	11.7	5	6.5	−4
5-8	1	1.3	2	2.6	−1
6-8	1	1.3	1	1.3	0
Total [1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–5. NET CHANGE IN EDUCATIONAL REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

GED level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	1.3	0	0	−1
2	14	18.2	10	13.0	−4
3	31	40.3	28	36.4	−3
4	29	37.7	36	46.8	+7
5	1	1.3	2	2.6	+1
6	1	1.3	1	1.3	0
Total [1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–6. NET CHANGE IN TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	2	2.6	4	5.2	+2
3	13	16.9	12	15.5	−1
4	11	14.3	15	19.5	+4
5	18	23.4	7	9.1	−11
6	10	13.0	7	9.1	−3
7	12	15.5	24	31.2	+12
8	11	14.3	8	10.4	−3
Total	77	100.0	77	100.0	0

Aptitudinal Requirements

Most of the current titles require no exceptional abilities in aptitudes except for spatial comprehension and, in fewer cases, form preception (see tables MA–7 to MA–16). Sizable minorities (37 percent and 29 percent, respectively) require above-average abilities in both these aptitudes. However, large majorities need only average mental abilities, motor coordination, manual dexterity, and finger dexterity and below-average clerical perception, eye-hand-foot coordination, and color discrimination. Superior mental abilities tended to be required by professionals, technicians, and some inspectors and supervisors; superior spatial comprehension, form perception, finger dexterity, and manual dexterity were required by skilled tool and die makers, all-around machinists, and many but not all combined setup men operators.

Except for finger and manual dexterity, the aptitudes required by new and continuing titles are not too different (see tables MA–7 to MA–16). Relatively more new than continuing titles require above average, and relatively fewer below average, manual and finger dexterity. Nonetheless, the proportion of new titles requiring exceptional abilities in either is still small (one-fifth or less). A slightly larger proportion of the new titles also requires average instead of below-average spatial comprehension and average instead of above-average motor coordination.

There are many more differences between past and present aptitudes needed by continuing titles than between those currently needed by new and all continuing titles (see tables MA–17 to MA–26). Continuing titles had increases in the requirements of a number of aptitudes, with increases often in the same direction as those of new titles. On a net basis, more continuing titles now require average instead of below-average verbal ability, numerical ability, and clerical perception; and more now require some, instead of almost no, color discrimination. Moreover, similar to development among the new titles, more continuing ones now need above-average spatial comprehension and average or better finger dexterity, instead, in both cases, of inferior amounts. In addition, and contrary to developments among new titles, more continuing titles now need average amounts of motor coordination, an increase largely at the expense of those needing below average, but in some cases at the expense of those needing above average amounts of this aptitude. Most of these changes in aptitudinal requirements involved moderate net changes: that is, movement of about 10 to 15 percent. However, in the case of verbal ability the net change was small, and in the case of clerical perception, large.

In the other direction, continuing titles now require less learning ability, manual dexterity, and form perception. There was a decrease in the net number of continuing titles needing at least average learning ability and an increase in those needing below average; and a decrease in those needing above-average manual dexterity and form perception but an increase in those needing average abilities in both. In no cases were the net numbers involved large.

The net gains of continuing titles in finger dexterity, spatial comprehension, and motor coordination correspond to the differences between the aptitudinal needs of new and continuing titles, but the drop in manual dexterity does not.

Nevertheless, there is evidence of a gain in the proportion of continuing and new titles now needing more finger dexterity and spatial comprehension, of new but not continuing titles now needing more manual dexterity, and of continuing but not new titles now needing more verbal ability, clerical perception, motor coordination, numerical ability, and color discrimination. On the other hand, continuing titles lost ground in learning ability, manual dexterity, and form perception. On balance, there seem to have been increases in needed amounts of at least one dexterity aptitude, three perpetual aptitudes, and two special mental aptitudes, as well as changes in the importance of some; but decreases in a key mental aptitude and key perceptual aptitudes. However, the magnitude of these changes differs; some involve few and others moderate net changes, and one, clerical perception, involves a substantial number. Verbal ability and learning ability are in the first category, with the remaining aptitudes in the second.

It is difficult to generalize about the characteristics of the titles whose aptitudinal needs have changed. However, semiskilled titles are disproportionately represented among those needing greater numerical ability, clerical perception, and motor coordination, and less general learning ability. That is, generally they require more ability to calculate and do paperwork and more physical coordination. Skilled titles in turn are disproportionately represented among those needing less manual dexterity and more spatial comprehension.

On balance, the nature of the aptitudes required in machine shop activities has changed, but it is difficult to say with what effects on skill levels. Among the new titles, there have been net gains in manual and finger dexterity and to some extent in spatial comprehension and motor coordination as well. Among continuing titles there have been moderate net losses, as measured by the net number of changes in manual dexterity and form perception, and small net losses in learning ability; these were countered by a large net gain in clerical perception, by moderate gains in spatial comprehension, motor coordination, finger dexterity, color discrimination, and numerical ability, and by a small gain in verbal ability. However, only in finger dexterity and spatial comprehension did the increase involve moves to above average amounts. Thus, ignoring offsetting increases and decreases, and taking account of the new levels achieved, there have been significant gains in finger dexterity, spatial comprehension, and clerical perception; modest gains in numerical ability; and slim gains in verbal ability and color discrimination; but a small net loss in learning ability. All in all, these changes in aptitudes suggest some overall gain in skill requirements.

TABLE MA–7. CURRENT COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Composite aptitude ratings[1]	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
121	1	0.9	0	0	1	0.6
222	3	2.7	0	0	3	1.8
231	0	0	1	1.8	1	.6
233	3	2.7	0	0	3	1.8
332	0	0	1	1.8	1	.6
333	58	51.2	29	50.9	87	51.2
334	3	2.7	2	3.5	5	2.9
343	15	13.3	12	21.0	27	15.9
344	15	13.3	3	5.3	18	10.6
444	14	12.4	9	15.8	23	13.5
445	1	.9	0	0	1	.6
Total[2]	113	100.0	57	100.0	170	100.0

[1] The first number is the general learning ability (G) rating; the second verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

TABLE MA–8. CURRENT GENERAL LEARNING ABILITY (G) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.9	0	0	1	0.6
2	6	5.3	1	1.8	7	4.1
3	91	80.5	47	82.5	138	81.2
4	15	13.3	9	15.8	24	14.1
5	0	0	0	0	0	0
Total[1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–9. CURRENT VERBAL ABILITY (V) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	4	3.5	0	0	4	2.4
3	64	56.6	33	57.9	97	57.1
4	45	39.8	24	42.1	69	40.6
5	0	0	0	0	0	0
Total[1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–10. CURRENT NUMERICAL ABILITY (N) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.9	1	1.8	2	1.2
2	3	2.7	1	1.8	4	2.4
3	76	67.3	41	71.9	117	68.8
4	32	28.3	14	24.6	46	27.1
5	1	0.9	0	0	1	0.6
Total[1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–11. CURRENT CLERICAL PERCEPTION (Q) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	13	11.5	2	3.5	15	8.8
4	94	83.2	54	94.7	148	87.1
5	6	5.3	1	1.8	7	4.1
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–12. CURRENT COORDINATION REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Motor coordination (K)					
1	0	0	0	0	0	0
2	4	3.5	0	0	4	2.4
3	94	83.2	55	96.5	149	87.7
4	15	13.3	1	1.8	16	9.4
5	0	0	1	1.8	1	.6
Total [1]	113	100.0	57	100.0	170	100.0
	b. Eye-hand-foot coordination (E)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	1	.9	0	0	1	.6
4	3	2.7	3	5.3	6	3.5
5	109	96.5	54	94.7	163	95.9
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–13. CURRENT DEXTERITY REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Manual dexterity (M)					
1	0	0	0	0	0	0
2	17	15.1	11	19.3	28	16.5
3	91	80.5	45	78.9	136	80.0
4	5	4.4	1	1.8	6	3.5
5	0	0	0	0	0	0
Total [1]	113	100.0	57	100.0	170	100.0
	b. Finger dexterity (F)					
1	0	0	0	0	0	0
2	15	13.3	10	17.5	25	14.7
3	79	69.9	41	71.9	120	70.6
4	19	16.8	6	10.5	25	14.7
5	0	0	0	0	0	0
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–14. CURRENT SPATIAL COMPREHENSION (S) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.9	1	1.8	2	1.2
2	43	38.0	17	29.8	60	35.3
3	55	48.7	32	56.1	87	51.2
4	14	12.4	7	12.3	21	12.4
5	0	0	0	0	0	0
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–15. CURRENT FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.9	0	0	1	0.6
2	32	28.3	17	29.8	49	28.8
3	73	64.6	35	61.4	108	63.5
4	7	6.2	5	8.8	12	7.1
5	0	0	0	0	0	0
Total	113	100.0	57	100.0	170	100.0

TABLE MA–16. CURRENT COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	2	1.8	1	1.8	3	1.8
4	28	24.8	4	7.0	32	18.8
5	83	73.5	52	91.2	135	79.4
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–17. NET CHANGES IN COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Composite aptitude ratings [1]	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
111	0	0	1	1.3	+1
121	1	1.3	0	0	−1
222	2	2.6	2	2.6	0
232	1	1.3	0	0	−1
233	2	2.6	2	2.6	0
333	30	39.0	40	51.9	+10
334	5	6.5	2	2.6	−3
335	1	1.3	0	0	−1
343	7	9.1	9	11.7	+2
344	15	19.5	10	13.0	−5
345	6	7.8	0	0	−6
444	3	3.9	10	13.0	+7
445	4	5.2	1	1.3	−3
Total [2]	77	100.0	77	100.0	0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

TABLE MA-18. NET CHANGE IN GENERAL LEARNING ABILITY (G) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	1.3	1	1.3	0
2	5	6.5	4	5.2	−1
3	64	83.1	61	79.2	−3
4	7	9.1	11	14.3	+4
5	0	0	0	0	0
Total	77	100.0	77	100.0	0

TABLE MA-19. NET CHANGE IN VERBAL ABILITY (V) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	1	1.3	+1
2	3	3.9	2	2.6	−1
3	39	50.6	44	57.1	+5
4	35	45.5	30	39.0	−5
5	0	0	0	0	0
Total	77	100.0	77	100.0	0

TABLE MA-20. NET CHANGE IN NUMERICAL ABILITY (N) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	1.3	1	1.3	0
2	3	3.9	2	2.6	−1
3	39	50.6	51	66.2	+12
4	23	29.9	22	28.6	−1
5	11	14.3	1	1.3	−10
Total	77	100.0	77	100.0	0

TABLE MA-21. NET CHANGE IN CLERICAL PERCEPTION (Q) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	3	3.9	+3
3	2	2.6	68	88.3	+66
4	59	76.6	6	7.8	−53
5	16	20.8	0	0	−16
Total	77	100.0	77	100.0	0

TABLE MA-22. NET CHANGE IN COORDINATION REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Motor coordination (K)				
1	0	0	0	0	0
2	6	7.8	3	3.9	−3
3	52	67.5	65	84.4	+13
4	19	24.7	9	11.7	−10
5	0	0	0	0	0
Total	77	100.0	77	100.0	0
	b. Eye-hand-foot coordination				
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	4	5.2	3	3.9	−1
5	73	94.8	74	96.1	+1
Total	77	100.0	77	100.0	0

TABLE MA-23. NET CHANGE IN DEXTERITY REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a; Manual dexterity (M)				
1	0	0	0	0	0
2	21	27.3	12	15.6	−9
3	52	67.5	62	80.5	+10
4	4	5.2	3	3.9	−1
5	0	0	0	0	0
Total	77	100.0	77	100.0	0
	b. Finger dexterity (F)				
1	0	0	0	0	0
2	5	6.5	11	14.3	+6
3	55	71.4	57	74.0	+2
4	17	22.1	9	11.7	−8
5	0	0	0	0	0
Total	77	100.0	77	100.0	0

TABLE MA-24. NET CHANGE IN SPATIAL COMPREHENSION (S) REQUIREMENT OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	3	3.9	0	0	−3
2	19	24.7	31	40.3	+12
3	38	49.4	35	45.5	−3
4	17	22.1	11	14.3	−6
5	0	0	0	0	0
Total[1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–25. NET CHANGE IN FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	1	1.3	+1
2	38	49.4	24	31.2	–14
3	35	45.5	50	64.9	+15
4	4	5.2	2	2.6	–2
5	0	0	0	0	0
Total[1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA–26. NET CHANGE IN COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	0	0	0
3	2	2.6	1	1.3	–1
4	5	6.5	19	24.7	+14
5	70	90.9	57	74.0	–13
Total	77	100.0	77	100.0	0

Temperamental Requirements

The dominant temperamental characteristics of machine-shop titles are evaluation and precision (see tables MA–27 and MA–28). A large proportion require both temperaments; only a small proportion involve repetitive tasks. Well over half the semiskilled[6] titles are characterized by evaluation and precision, and only one-third by repetitiveness, no discretion, or both. However, titles involving the last two characteristics, even though they involve evaluation and precision as well, are almost all semiskilled on unskilled. Most skilled titles are characterized by evaluation and precision, either alone or combined with variation, directing and controlling, or both. Where precision is not needed, skilled titles are supervisory.

Moreover, relatively more new than continuing titles require evaluation and precision together, and relatively fewer require each alone (see tables MA–27 and MA–28). Relatively fewer new titles also seem to have significant temperamental attributes, such as variation or repetitiveness. To some extent, this probably reflects no more than improved description and analysis.

A comparison of the past and present temperaments of continuing titles with two sets of worker traits also shows a net rise in the number requiring both evaluation and precision and a net drop in those requiring precision alone (see tables MA–29 and MA–30). However, this again may be more a matter of better description and analysis than an actual change in temperamental needs.

In all, 49 of the 77 continuing titles had changes in required temperaments. As the previous comparisons suggest, the most common was the addition of evaluation (to 43 of the 49 titles), most often to titles that were repetitive (29) and which lost this characteristic (22 of the 29). Two-thirds of the titles whose temperaments now include evaluation were semiskilled. In contrast over two-thirds of the titles whose temperaments did not change were skilled; most already required evaluation and precision. The temperaments of five titles, all either semiskilled or unskilled, changed to include repetitiveness or lack of discretion.

To what extent did the addition of evaluation to the temperaments of continuing titles reflect actual changes in skill? It is difficult to say. Of the 43 titles affected, educational requirements rose for only 12 and fell for 1, but training requirements rose for 12 and fell for 13. Overall, educational requirements rose, typically to the third level for semiskilled and the fourth for skilled titles, but training requirements did not rise. This gain in educational levels may reflect the titles that now need evaluation.

To summarize, more continuing, and particularly semiskilled titles, require evaluation; and relatively more new ones need both evaluation and precision rather than one or the other alone. The similarity of the developments with respect to both new and continuing titles suggest that skill requirements in the industry have risen.

Worker Functions

The pattern of worker functions reflects the importance of operating and setting up machine tools and of precision in machine-shop activities. Operating-controlling, setting up, and precision working typify, respectively, 34 percent, 25 percent, and 16 percent of the titles (see tables MA–31 and MA–32). Low-skilled handling, feeding-offbearing, and tending functions characterize only one quarter of the titles. The importance of data functions also is apparent: One-third of the titles involve the analysis of data.

Worker functions of the new titles differ significantly from those of the continuing (see tables MA–31 and MA–32). Substantially more, relatively, of the new titles involve low-skilled han-

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[6] Using classifications of the second edition of the D.O.T.

TABLE MA-27. CURRENT TEMPERAMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Precision	1	0.9	0	0	1	0.6
As well as:						
Repetitiveness and no discretion	3	2.7	3	5.3	6	3.5
Repetitiveness	10	8.9	1	1.8	11	6.5
Variation	2	1.8	0	0	2	1.2
Total precision [1]	16	14.2	4	7	20	11.8
Evaluation	2	1.8	1	1.8	3	1.8
As well as:						
Repetitiveness	0	0	1	1.8	1	.6
Variation	2	1.8	0	0	2	1.2
Variation, directing, and dealing with people	5	4.4	0	0	5	2.9
Total evaluation [1]	9	8	2	3.5	11	6.5
Evaluation and precision	60	53.1	38	66.7	98	57.6
As well as:						
Repetitiveness and no discretion	1	.9	0	0	1	.6
Repetitiveness	10	8.9	3	5.3	13	7.7
Variation	5	4.4	5	8.8	10	5.9
Interpretation	2	1.8	0	0	2	1.2
Directing, including dealing with people	1	.9	2	3.5	3	1.8
Directing and variation	1	.9	0	0	1	.6
Directing, dealing with people and variation	3	2.7	0	0	3	1.8
Total evaluation and precision [1]	83	73.5	48	84.2	131	77.1
All others: Repetitiveness and no discretion	5	4.4	3	5.3	8	4.7
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not add up to their respective totals because of rounding.

TABLE MA-28. SELECTED CURRENT TEMPERAMENTS OF REPETITIVENESS, VARIATION, NO DISCRETION AND DIRECTING, CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Repetitiveness and no discretion	9	8	6	10.5	15	8.8
Repetitiveness	20	17.7	5	8.8	25	14.7
Variation	18	15.9	5	8.8	23	13.5
Directing, including dealing with people	10	8.8	2	3.5	12	7.1
All others	56	49.6	39	68.4	95	55.9
Total	113	100.0	57	100.0	170	100.0

TABLE MA-29. NET CHANGE IN TEMPERAMENTS OF CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Precision as well as:					
Repetitiveness and no discretion	0	0	1	1.3	+1
Repetitiveness	27	35.1	8	10.4	−19
Variation	11	14.3	2	2.6	−9
Total precision	38	49.4	11	14.3	−27
Evaluation and directing	1	1.3	0	0	−1
Evaluation and precision	33	42.9	47	61.0	+14
As well as:					
Repetitiveness	0	0	8	10.4	+8
Variation	0	0	5	6.5	+5
Interpretation	0	0	1	1.3	+1
Directing and variation	0	0	1	1.3	+1
Total evaluation and precision	33	42.9	62	80.5	+29
All others: Repetitiveness and no discretion	5	6.5	4	5.2	−1
Total [1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA-30. NET CHANGE IN SELECTED TEMPERAMENTS OF REPETITIVENESS, VARIATION AND NO DISCRETION, CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Repetitiveness and no discretion	5	6.5	5	6.5	0
Repetitiveness	27	35.1	16	20.8	−11
Variation	11	14.3	8	10.4	−3
All others	34	44.2	48	62.3	+14
Total [1]	77	100.0	77	100.0	0

[1] Percentages may not total 100 percent because of rounding.

dling, feeding-offbearing, and tending functions; and substantially fewer, relatively, involve higher skilled manipulating, operating, controlling, and supervising. Moreover, considerably fewer, relatively, of the new titles involve more complex data functions and, to a smaller extent, data functions at all. Analyzing and synthesizing data are part of nearly two-fifths of the continuing titles but less than 30 percent of the new.

On the other hand, a somewhat larger proportion of the new than continuing titles involve high-skilled precision working, considered more complex than manipulating or operating-controlling (see table MA-31). However, this difference does not seem to compensate for the relatively fewer new titles that involve manipulating, operating-controlling, and supervising functions.

On the average, the new titles seem to be less skilled than the continuing and indicate a polarization of titles into two groups: Simple handling and tending on the one hand, and more advanced precision working titles requiring less involvement with complex data functions on the other.

TABLE MA-31. WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Primarily involving things:						
Handling	2	1.8	0	0	2	1.2
Feeding-offbearing	0	0	1	1.8	3	1.8
Tending	8	7.1	9	15.8	17	10.0
Manipulating	13	11.5	1	1.8	14	8.2
Operating-controlling	23	20.4	15	26.3	37	21.8
Precision working	1	.9	4	7	5	2.9
Setting up	1	.9	4	7	5	2.9
Primarily involving things and data:						
Operating-controlling and comparing	2	1.8	0	0	2	1.2
Operating-controlling and computing	0	0	1	1.8	1	.6
Operating-controlling and compiling	1	.9	0	0	1	.6
Operating-controlling and analyzing	12	10.6	5	8.8	17	10.0
Precision working and compiling	3	2.7	2	3.5	7	4.1
Precision working and analyzing	8	7.1	4	7	12	7.1
Precision working and synthesizing	3	2.7	0	0	3	1.8
Setting up and computing	1	.9	1	1.8	2	1.2
Setting up and compiling	6	5.3	3	5.3	9	5.3
Setting up and analyzing	20	17.7	7	12.3	27	15.9
Primarily involving data and people:						
Coordinating and supervising	2	1.8	0	0	2	1.2
Primarily involving data, things and people:						
Driving-controlling, coordinating and supervising	1	.9	0	0	1	.6
Precision working, coordinating and supervising	6	5.3	0	0	6	3.5
Total [1]	113	100.0	57	100.0	170	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MA-32. SELECTED DATA WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Data worker functions	Continuing titles		New titles		All continuing titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Comparing	2	1.8	0	0	2	1.2
Computing	1	.9	2	3.5	3	1.8
Compiling	10	8.8	5	8.8	15	8.8
Analyzing	40	35.4	16	28.1	56	32.9
Synthesizing	3	2.7	0	0	3	1.8
None or not primary	57	50.4	34	59.6	91	53.5
Total	113	100.0	57	100.0	170	100.0

Changes in Occupational Content

Few definitions were left unchanged. Many of the changes were complex, defying easy classification or determination of changes in skill requirements. Three types of changes were prevalent: The addition of optional duties; the inclusion of a number of new or additional tasks; and the broadening of operative assignments to incorporate setting up. The overall tenor was the enlargement of duties included in a title (see tables MA-33 and MA-38).

Surprisingly, evidence of new equipment, including automated systems, appeared in just 5 of the 113 continuing titles. Explicit changes in methods appeared in only three.

Optional duties were added to 81 of the 113, but were the sole changes in only 21 (see tables MA-33 and MA-34). These additions seemed designed to account for variations in job content in different establishments and did not seem to alter the general skill level required by the title.

Thirty-one titles incorporated extra tasks or activities (see tables MA-33 and MA-35). Nearly all were accompanied by other changes, exclusive of the addition of optional duties. In some cases, extra tasks or activities represented more detailed descriptions of the duties of the title; in others, they represented new assignments; and in still others they resulted from possible changes in methods. These additions did not seem to require any different skills. For example, one operative title now includes turning valves to direct a flow of coolant against a wheel; another listening for noises indicating effective meshing of gears. Again, an operative-setup title now includes changing worn grinding wheels; another, using wrenches to change worn cutters. A skilled inspector now adjusts new and reworked tools and dies; another uses specialized testing equipment to test the operation of mechanical assemblies.

Setting up duties were added to 47 titles, but were the only changes, excluding the addition of optional duties, in just 28. Only five titles required closer tolerances and only eight, more computations (see tables MA-33 and MA-36).

It is difficult to show that these content changes actually involved changes in skill requirements. For example, among the 10 titles with no change in their definitions and for which there are both past and present worker traits, a net [7] of 10 percent needed more education and training; 20 percent, more clerical perception, motor coordination, and manual dexterity; 40 percent, more finger dexterity; and a net of 70 percent, more color discrimination (although in the last case, new levels are still below average). In contrast, larger net percentages of titles with changes in content, including the addition of optional duties, had increases in educational and training but not necessarily in aptitudinal or temperamental requirements. Moreover, most of the titles with content changes

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[7] After subtracting titles with decreases.

Table MA-33. Changes in Occupational Content of All Continuing Occupational Titles in Machine-Shop Activities by Number of Titles With Singular and Multiple Changes

Type of change	Single changes		Multiple changes						Total changes [1]	
			Includes only optional tasks		Includes all other changes		All multiple changes			
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
No change	18	100.0	0	0	0	0	0	0	18	100.0
Added tasks:										
Optional	21	25.6	21	25.6	40	48.8	61	74.4	82	100.0
Extra	2	6.5	12	38.7	17	54.8	29	93.5	31	100.0
Setting up	4	8.5	24	51.1	19	40.4	43	91.5	47	100.0
Computations	1	10.0	1	10.0	8	80.0	9	90.0	10	100.0
Total added tasks	28	16.5	58	34.1	84	49.4	142	83.5	170	100.0
Fewer tasks	1	100.0	0	0	0	0	0	0	1	100.0
Closer tolerances	0	0	0	0	6	100.0	6	100.0	6	100.0
Other	3	37.5	2	25.0	3	37.5	5	62.5	8	100.0

[1] Percentages may not add to respective totals because of rounding.

had multiple changes so that it was impossible to connect them to specific changes in worker trait requirements.

The few titles (three at most) which involved automation showed no evidence of skill increases. On the contrary, they had net decreases in educational and training needs, and in a majority of aptitudinal abilities. However, evaluating was added to the temperaments required of all three.

Although it is difficult to demonstrate that various changes in occupational content actually led to increases or decreases in skill levels, there is little evidence of a decline in skills. Only one title had an apparent decline, the result of the elimination of duties that considerably narrowed its title. On balance, then, changes in occupational content do not indicate an overall change in skill levels.

Table MA-34. Types of Changes in Occupational Content Combined With Optional Tasks, All Continuing Occupational Titles in Machine-Shop Activities by Number of Titles

Types of changes	Abilities number	Percent
Optional tasks alone	21	25.9
Optional tasks plus extra tasks	12	14.8
Setting up	24	29.6
Computations	1	1.2
New equipment	2	2.5
Extra tasks and setting up	11	13.6
Extra tasks and computations	2	2.5
Extra tasks and closer tolerances	1	1.2
Setting up and computations	2	2.5
Setting up and closer tolerances	1	1.2
Computations and closer tolerances	1	1.2
Extra tasks, setting up and computations	1	1.2
Extra tasks, setting up, computations and closer tolerances	1	1.2
Setting up, computations, closer tolerances and new methods	1	1.2
Total multiple changes [1]	60	74.1
Total changes [1]	81	100.0

[1] Percentages may not add to respective totals because of rounding.

Table MA-35. Types of Changes in Occupational Content Combined With Extra Tasks, All Continuing Occupational Titles in Machine-Shop Activities by Number of Titles

Types of changes	Abilities number	Percent
Extra tasks alone	2	6.5
Extra tasks plus:		
Optional tasks	12	38.7
Setting up	1	3.2
Optional tasks and setting up	11	35.5
Optional tasks and computations	2	6.5
Optional tasks and closer tolerances	1	3.2
Optional tasks, setting up and computations	1	3.2
Optional tasks, setting up, computations and closer tolerances	1	3.2
Total multiple changes	29	93.5
Total changes	31	100.0

Table MA-36. Types of Changes in Occupational Content Combined With Setting Up, All Continuing Occupational Titles in Machine-Shop Activities by Number of Titles

Types of changes	Abilities number	Percent
Setting up alone	4	8.5
Setting up plus:		
Optional tasks	24	51.1
Extra tasks	1	2.1
New equipment	1	2.1
Optional tasks and extra tasks	11	23.4
Optional tasks and computations	2	4.3
Optional tasks and closer tolerances	1	2.1
Optional tasks, extra tasks and computations	1	2.1
Optional tasks, extra tasks, computations, and closer tolerances	1	2.1
Optional tasks, computations, closer tolerances and new methods	1	2.1
Total multiple changes [1]	43	91.5
Total changes [1]	47	100.0

[1] Percentages may not add to respective totals because of rounding.

TABLE MA-37. TYPES OF CHANGES IN OCCUPATIONAL CONTENT COMBINED WITH COMPUTATIONS, ALL CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Types of changes	Abilities number	Percent
Computations alone	1	10
Computations plus:		
Optional tasks	1	10
Optional tasks and extra tasks	2	20
Optional tasks and setting up	2	20
Optional tasks and closer tolerances	1	10
Optional tasks, extra tasks and setting up	1	10
Optional tasks, extra tasks, setting up and closer tolerances	1	10
Optional tasks, setting up, closer tolerances, and new methods	1	10
Total multiple changes	9	90
Total	10	100

TABLE MA-38. TYPES OF CHANGES IN OCCUPATIONAL CONTENT COMBINED WITH CLOSER TOLERANCES, ALL CONTINUING OCCUPATIONAL TITLES IN MACHINE-SHOP ACTIVITIES BY NUMBER OF TITLES

Types of changes	Abilities number	Percent
Closer tolerances alone	0	0
Closer tolerances plus:		
New equipment	1	16.7
Optional tasks and extra tasks	1	16.7
Optional tasks and setting up	1	16.7
Optional tasks and computations	1	16.7
Optional tasks, extra tasks, setting up and computations	1	16.7
Optional tasks, setting up, computations and new methods	1	16.7
Total multiple changes	6	100.0
Total [1]	6	100.0

[1] Percentages may not total 100 percent because of rounding.

Conclusions

There is evidence to support both an overall increase or decrease in skill requirements in machine shop occupations. Educational and training requirements of continuing titles have risen, despite some polarization. However, the large number of new titles need less education on the average than the continuing ones and include relatively fewer titles that need either a great deal or very little training. These conflicting educational and training developments suggest no net change in skill levels. Changes in occupational content, while numerous and complicated, indicate much the same. On the other hand, the worker functions of new titles contain proportionately more low and medium skilled titles than the continuing titles and indicate a decline in skill levels. Changes in aptitudinal and temperamental requirements, however, contradict evidence of either no change or a drop in skills. The aptitudinal changes are complex but, on balance, point to some skill increases. The temperamental changes point in the same direction; more continuing titles involve evaluation and more new titles, both evaluation and precision, instead of one or the other alone.

Medical Services

Educational and Vocational Requirements

There was a moderate increase in the educational requirements of the continuing titles but very little in their vocational requirements. The number of titles with somewhat above-average educational needs (e.g., level 4) declined, but the number of those with even greater educational needs increased. However, as a possible foretaste of the future, the new titles, on the average, require substantially less education and training than all continuing ones.

The 46 continuing titles with two sets of worker traits data[1] originally were concentrated at the fourth level or higher of educational development, and for the most part still are (see tables MS-1 and MS-2). These levels include over 90 percent of the titles. Nevertheless, there was a moderate shift upwards. The number of titles requiring the fifth and sixth levels of development has increased, while the number needing the fourth level has decreased.

There was only a slight net increase in the amount of training required by these titles (see tables MS-1 and MS-3). Thirty-three continuing titles (72 percent) formerly needed over 2 years compared to 35 (76 percent) which do now. These gains were offset by a net drop in titles requiring from 6 months to 2 years' preparation.

It is difficult to generalize about the types of titles whose educational and training requirements changed. Attendants and practical nurses now need less training; occupational therapists, physical therapists, and veterinarian attendants, less education. On the other hand, a number of medical technicians and laboratory assistants now need more training; while housekeepers, nurses with specialized assignments (including administrative), and various professional medical specialists, as well as general practitioners, need more education. The increases in training and education tended to be concentrated somewhat among professional and technical titles, especially highly specialized ones. However, titles whose educational needs did not change were chiefly those of medical professionals, but also a few medical technicians, general-duty nurses, and orderlies.

A disproportionate number of new titles had relatively low educational requirements compared to all continuing titles (see tables MS-4 and MS-

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[1] About two-thirds of these titles are professional, and nearly one-quarter, technicians and therapists; the remainder are service occupations. The occupational distribution of all titles in medical services is much the same.

5). Three-fifths of the new titles needed no more than the third level of educational development compared to barely one-fifth of all continuing titles. Further, relatively few new titles required advanced levels of education—just 19 percent compared to over 60 percent of the continuing titles. Nineteen percent is not an insignificant fraction, even though it is less than expected.

The new titles also showed some net decline in vocational requirements (see tables MS–4 and MS–6). Although about two-fifths of the new titles still need substantial amounts of vocational preparation, the proportion is well below that of all continuing titles. Further, a substantially larger proportion of the new titles need less than 3 months' training (20 percent of the new compared to 7 percent of the continuing) or need from 3 months' to a year's training (28 percent of the new compared to 14 percent of the continuing).

Accounting for the greater part of the 41 new titles were dental technicians (15), attendants and aides (7), and clerks (8). In addition, three were medical professionals (all specialists), three technicians (including one teacher), and three therapists. Only one was a dental professional. A characteristic of the new titles was intense specialization, especially among dental technicians.

Manual, service, and clerical titles now are concentrated at the second and third levels of educational development; aids and attendants at the third; technicians at the fourth and to some extent the fifth; nurses and administrators at the fifth; and professionals at the sixth, the highest. Most of the manual and service titles now require either very little vocational preparation (a short demonstration up to 30 days) or modest amounts (1 to 3 months), while attendants rarely need more than 3 months. Aids and assistants need 6 months to 2 years; technicians and therapists, a minimum of 3 to 6 months but usually 1 to 2 years; nurses, 2 to 4 years; administrators, at least 1 to 2 years but usually 2 to 10; and professionals, 4 to 10 years.

TABLE MS–1. NET CHANGE IN EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

GED-SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1-1	0	0	1	2.2	+1
1-2	0	0	0	0	0
1-3	1	2.2	0	0	−1
2-3	0	0	0	0	0
2-4	1	2.2	1	2.2	0
3-3	0	0	1	2.2	+1
3-4	0	0	1	2.2	+1
3-5	0	0	0	0	0
3-6	2	4.3	0	0	−2
4-1	0	0	0	0	0
4-2	0	0	0	0	0
4-3	0	0	0	0	0
4-4	2	4.3	1	2.2	−1
4-5	2	4.3	1	2.2	−1
4-6	5	10.9	4	8.7	−1
4-7	7	15.2	3	6.5	−4
4-8	0	0	2	4.3	+2
5-6	0	0	1	2.2	+1
5-7	5	10.9	9	19.6	+4
5-8	4	8.7	0	0	−4
6-8	17	37.0	21	45.7	+4
Total[1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MS–2. NET CHANGE IN EDUCATIONAL REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

GED level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	2.2	1	2.2	0
2	1	2.2	1	2.2	0
3	1	2.2	2	4.3	+1
4	16	34.8	11	23.9	−5
5	9	19.6	10	21.7	+1
6	18	39.1	21	45.7	+3
Total[1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MS–3. NET CHANGE IN TRAINING REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	1	2.2	+1
2	0	0	0	0	0
3	1	2.2	1	2.2	0
4	3	6.5	3	6.5	0
5	2	4.3	1	2.2	−1
6	7	15.2	5	10.9	−2
7	12	26.1	12	26.1	0
8	21	45.7	23	50.0	+2
Total[1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Aptitudinal Requirements

A majority of all titles now require superior learning ability, clerical perception, and verbal ability; and somewhat fewer than two-fifths require superior numerical ability, spatial comprehension, form perception, and finger dexterity (see tables MS–7 and MS–16). However, comparatively few titles now need more than average manual dexterity, both types of coordination, and color discrimination.

Chiefly professional, technical, and administrative titles need superior learning and verbal abilities; certain professional and technical titles (e.g., research) need superior numerical ability; administrative titles need superior clerical perception. Titles with above average requirements in form perception, manual and finger dexterity, and color discrimination are primarily professional and technical specialties with unique needs. For example, TABLE MS-4. CURRENT EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

GED-SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1-1	1	0.8	0	0	1	0.6
2-2	2	1.7	3	7.3	5	3.1
2-3	0	0	1	2.4	1	.6
2-4	2	1.7	1	2.4	3	1.9
2-5	0	0	0	0	0	0
2-6	0	0	2	4.9	2	1.3
3-1	0	0	0	0	0	0
3-2	1	.8	1	2.4	2	1.3
3-3	5	4.2	4	9.8	9	5.6
3-4	6	5.0	5	12.2	11	6.9
3-5	3	2.5	4	9.8	7	4.4
3-6	2	1.7	2	4.9	4	2.5
3-7	0	0	1	2.4	1	.6
4-4	2	1.7	1	2.4	3	1.9
4-5	3	2.5	0	0	3	1.9
4-6	10	8.4	0	0	10	6.3
4-7	5	4.2	7	17.1	12	7.5
4-8	4	3.4	1	2.4	5	3.1
5-6	4	3.4	1	2.4	5	3.1
5-7	26	21.9	4	9.8	30	18.8
5-8	5	4.2	0	0	5	3.1
6-8	38	31.9	3	7.3	41	25.6
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MS-5. CURRENT EDUCATIONAL REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

GED level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.8	0	0	1	0.6
2	4	3.4	7	17.1	11	6.9
3	17	14.3	17	41.5	34	21.3
4	24	20.2	9	22.0	33	20.6
5	35	29.4	5	12.2	40	25.0
6	38	31.9	3	7.3	41	25.6
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE MS-6. CURRENT TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.8	0	0	1	0.6
2	3	2.5	4	9.8	7	4.4
3	5	4.2	5	12.2	10	6.3
4	10	8.4	7	17.1	17	10.6
5	6	5.1	4	9.8	10	6.3
6	16	13.4	5	12.2	21	13.1
7	31	26.1	12	29.3	43	26.9
8	47	39.5	4	9.8	51	31.9
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

considerable manual and finger dexterity was required by dentists and certain pathologists.

New titles seem to need less proficiency in most aptitudes than continuing titles (see tables MS-7 to MS-16). Considerably smaller proportions of the newer than continuing titles require superior learning, verbal, and numerical abilities, clerical perception, or manual dexterity; and larger proportions require below-average spatial comprehension, motor coordination, and possibly color discrimination. Finger dexterity is the only aptitude in which the requirements of new titles are greater than continuing, and the difference is only in the proportions needing average instead of below-average capabilities. There is little difference between new and continuing titles with respect to eye-hand-foot coordination and form perception.

The most important differences between past and present aptitudes of the 46 continuing titles with two profiles of worker traits are (a) the net increase in those needing superior numerical ability and manual dexterity; (b) the net increase in those needing the highest degree of form perception and spatial comprehension without any change in the size of the above-average category as a whole; and (c) the net decrease in those needing superior motor coordination and average color discrimination (see tables MS-17 to MS-26). There was no change in the numbers needing various amounts of general learning ability or finger dexterity, and very little in those needing various amounts of verbal ability. The shift in clerical perception was towards average from both above and below; and in eye-hand-foot coordination, the very bottom to the next level with no change in the number in below-average categories.

The gross increases in numerical ability were concentrated among medical professionals, but also included a medical technician, a nurse engaged in administrative duties, and two service occupations; the few decreases were limited to an attendant and a technician. Increases in form perception and manual dexterity were concentrated among professional titles; and increases in spatial comprehension, as well as in eye-hand-foot coordination, finger dexterity, and clerical perception, among professionals and technicians, including nurses. Decreases in motor coordination and color discrimination, as well as in finger dexterity, also were concentrated among professionals. The few increases in learning ability were confined to one type of nurse; the decreases to a few attendants and one medical technician. The few decreases in verbal ability were concentrated among professionals but included two technicians and two service occupations; the one increase was confined to a medical professional.

Aptitudes of a disproportionately large number of professional titles seem to have been changed. About half the titles with such changes were professional; but these constituted only about one-quarter of all the titles studied. In general, these professional titles seem to need greater ability of a quantitative and less of a verbal nature, perhaps

Table MS-7. Current Composite Intelligence Requirements (GVN) of Continuing New Occupational Titles in Medical Services by Number of Titles

Composite aptitude ratings[1]	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
111	1	0.8	0	0	1	0.6
112	23	19.3	0	0	23	14.4
113	3	2.5	1	2.4	4	2.5
121	8	6.7	1	2.4	9	5.6
122	1	.8	0	0	1	.6
123	1	.8	0	0	1	.6
131	2	1.7	1	2.4	3	1.9
212	3	2.5	1	2.4	4	2.5
213	2	1.7	0	0	2	1.3
221	0	0	2	4.9	2	1.3
222	16	13.4	3	7.3	19	11.9
223	14	11.8	1	2.4	15	9.4
232	2	1.7	0	0	2	1.3
233	8	6.7	2	4.9	10	6.3
234	0	0	2	4.9	2	1.3
333	10	8.4	8	19.5	18	11.3
334	12	10.1	5	12.2	17	10.6
343	1	.8	0	0	1	.6
344	2	1.7	6	14.6	8	5.0
345	0	0	1	2.4	1	.6
443	2	1.7	0	0	2	1.3
444	7	5.9	6	14.6	13	8.1
445	1	.8	1	2.4	2	1.3
Total[2]	119	100.0	41	100.0	160	100.0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

Table MS-8. Current General Learning Ability (G) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	39	32.8	3	7.3	42	26.3
2	45	37.8	11	26.8	56	35.0
3	25	21.0	20	48.8	45	28.1
4	10	8.4	7	17.1	17	10.6
5	0	0	0	0	0	0
Total	119	100.0	41	100.0	160	100.0

Table MS-9. Current Verbal Ability (V) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	32	26.9	2	4.9	34	21.2
2	40	33.6	7	17.1	47	29.4
3	34	28.6	18	43.9	52	32.5
4	13	10.9	14	34.1	27	16.9
5	0	0	0	0	0	0
Total	119	100.0	41	100.0	160	100.0

Table MS-10. Current Numerical Ability (N) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	11	9.2	4	9.8	15	9.4
2	45	37.8	4	9.8	49	30.6
3	41	34.5	12	29.2	53	33.1
4	21	17.7	19	46.3	40	25.0
5	1	.8	2	4.9	3	1.9
Total	119	100.0	41	100.0	160	100.0

Table MS-11. Current Clerical Perception (Q) Requirements of Continuing and New Occupational Titles on Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	16	13.5	1	2.4	17	10.6
3	58	48.7	14	34.2	72	45.0
4	44	37.0	23	56.1	67	41.9
5	1	.8	3	7.3	4	2.5
Total	119	100.0	41	100.0	160	100.0

Table MS-12. Current Coordination Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Motor coordination (K)					
1	0	0	0	0	0	0
2	20	16.8	5	12.2	25	15.6
3	46	38.7	15	36.6	61	38.1
4	51	42.9	21	51.2	72	45.0
5	2	1.7	0	0	2	1.3
Total[1]	119	100.0	41	100.0	160	100.0
	b. Eye-hand-foot coordination (E)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	2	1.7	2	4.9	4	2.5
4	53	44.5	17	41.5	70	43.8
5	64	53.8	22	53.6	86	53.7
Total	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

reflecting changes in the methodology and content of medicine and biology.

The aptitudinal requirements of new titles generally were lower than the continuing, except with respect to finger dexterity, which rose, and to form perception and motor coordination, which did not change. In contrast, continuing titles, on the average, now seemed to need more numerical ability, manual dexterity, form perception, spatial comprehension, and eye-hand-foot coordination, but less motor coordination and color discrimination, as well as a different pattern of clerical perception. There thus seemed to be basic differences between the new titles which included comparatively few professionals and the others. The new titles showed an overall drop in skill levels, and the continuing titles showed mixed developments, perhaps pointing to an increase in one mental and in certain manual and perceptual capabilities. Since the new titles constitute well over one-third of all the titles, a continuation of their pattern of an overall drop in skills could substantially alter the aptitudinal requirements of medical service occupations.

Table MS-13. Current Dexterity Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Manual dexterity (M)					
1	15	12.6	2	4.9	17	10.6
2	23	19.3	5	12.2	28	17.5
3	54	45.4	22	53.6	76	47.5
4	25	21.0	12	29.3	37	23.1
5	2	1.7	0	0	2	1.3
Total	119	100.0	41	100.0	160	100.0
	b. Finger dexterity (F)					
1	15	12.6	3	7.3	18	11.3
2	30	25.2	11	26.8	41	25.6
3	42	35.3	19	46.3	61	38.1
4	30	25.2	8	19.5	38	23.8
5	2	1.7	0	0	2	1.3
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

Table MS-14. Current Spatial Comprehension (S) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	29	24.4	3	7.3	32	20.0
2	18	15.1	10	24.4	28	17.5
3	42	35.3	11	26.8	53	33.1
4	29	24.4	16	39.0	45	28.1
5	1	.8	1	2.4	2	1.3
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

Table MS-15. Current Form Perception (P) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	25	21.0	3	7.3	28	17.5
2	20	16.8	11	26.8	31	19.4
3	42	35.3	15	36.6	57	35.6
4	31	26.1	12	29.3	43	26.9
5	1	.8	0	0	1	.6
Total	119	100.0	41	100.0	160	100.0

Table MS-16. Current Color Discrimination (C) Requirements of Continuing and New Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	7	5.9	2	4.9	9	5.6
3	32	26.9	9	22.0	41	25.6
4	36	30.3	19	46.3	55	34.4
5	44	37.0	11	26.8	55	34.4
Total[1]	119	100.0	41	100.0	160	100.0

[1] Percentages may not total 100 percent because of rounding.

Table MS-17. Net Change in Composite Intelligence Requirements (GVN) of Continuing Titles in Medical Services by Number of Titles

Composite Aptitude ratings[1]	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
111	1	2.2	0	0	−1
112	13	28.3	17	36.9	+4
113	7	15.2	0	0	−7
121	0	0	4	8.7	+4
222	4	8.7	5	10.9	+1
223	9	19.5	7	15.2	−2
232	0	0	1	2.2	+1
233	3	6.5	3	6.5	0
323	1	2.2	0	0	−1
333	4	8.7	5	10.9	+1
334	1	2.2	1	2.2	0
335	2	4.3	0	0	−2
444	0	0	2	4.8	+2
445	1	2.2	1	2.2	0
Total[2]	46	100.0	46	100.0	0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

Table MS-18. Net Change in General Learning Ability (G) Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	21	45.7	21	45.7	0
2	16	34.8	16	34.8	0
3	8	17.3	6	13.0	−2
4	1	2.2	3	6.5	+2
5	0	0	0	0	0
Total[1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table MS–19. Net Change in Verbal Ability (V) Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	21	45.7	17	37.0	−4
2	14	30.4	16	34.8	+2
3	10	21.7	10	21.7	0
4	1	2.2	3	6.5	+2
5	0	0	0	0	0
Total	46	100.0	46	100.0	0

Table MS–20. Net Change in Numerical Ability (N) Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	1	2.2	4	8.7	+3
2	17	36.9	23	50.0	+6
3	24	52.2	15	32.6	−9
4	1	2.2	3	6.5	+2
5	3	6.5	1	2.2	−2
Total	46	100.0	46	100.0	0

Table MS–21. Net Change in Clerical Perception (Q) Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	0	0	5	10.9	+5
3	7	15.2	23	50	+16
4	36	78.3	17	37	−19
5	3	6.5	1	2.2	−2
Total[1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table MS–22. Net Change in Coordination Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Motor coordination (K)				
1	5	10.9	0	0	−5
2	20	43.5	14	30.4	−6
3	14	30.4	22	47.9	+8
4	7	15.2	10	21.7	+3
5	0	0	0	0	0
Total	46	100.0	46	100.0	0
	b. Eye-hand-foot coordination (E)				
1	0	0	0	0	0
2	0	0	0	0	0
3	1	2.2	0	0	−1
4	12	26.1	30	65.2	+18
5	33	71.7	16	34.8	−17
Total	46	100.0	46	100.0	0

Table MS–23. Net Change in Dexterity Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Manual dexterity (M)				
1	3	6.5	11	23.9	+8
2	19	41.3	14	30.4	−5
3	22	47.9	20	43.5	−2
4	2	4.3	1	2.2	−1
5	0	0	0	0	0
Total	46	100.0	46	100.0	0
	b. Finger dexterity (F)				
1	12	26.1	12	26.1	0
2	14	30.4	14	30.4	0
3	17	37.0	16	34.8	−1
4	3	6.5	4	8.7	+1
5	0	0	0	0	0
Total	46	100.0	46	100.0	0

Table MS–24. Net Change in Spatial Comprehension (S) Requirements of Continuing Occupational Titles in Medical Services by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	14	30.4	20	43.5	+6
2	10	21.7	8	17.3	−2
3	18	39.2	13	28.3	−5
4	4	8.7	5	10.9	+1
5	0	0	0	0	0
Total	46	100.0	46	100.0	0

Temperamental Requirements

The great variety of temperamental combinations precludes a simple classification system. Instead it was necessary to isolate a number of partial patterns, noting, however, that they have been

TABLE MS–25. NET CHANGE IN FORM PERCEPTION (P) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	5	10.9	16	34.8	+11
2	24	53.1	12	26.1	−12
3	13	28.3	14	30.4	+1
4	4	8.7	4	8.7	0
5	0	0	0	0	0
Total	46	100.0	46	100.0	0

TABLE MS–26. NET CHANGE IN COLOR DISCRIMINATION (C) REQUIREMENTS OF CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	3	6.5	2	4.3	−1
3	29	63.1	22	47.9	−7
4	10	21.7	12	26.1	+2
5	4	8.7	10	21.7	+6
Total	46	100.0	46	100.0	0

TABLE MS–27. NET CHANGE IN TEMPERAMENTS OF PRECISION AND EVALUATION, CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Precision and evaluation	6	13.0	24	52.2	+18
Evaluation	21	45.7	9	19.6	−12
Precision	10	21.7	10	21.7	0
All others	9	19.6	3	6.5	−6
Total	46	100.0	46	100.0	0

taken out of context and usually are associated with other temperaments as well.

Many more of the 46 continuing titles with two worker trait profiles now require both precision and evaluation, and involve variation (although not necessarily more discretion), directing, controlling, planning, and dealing with and influencing people (see tables MS–27 to MS–32). It is difficult to say if these changes accurately reflect changes in work content; to some unknown degree, they reflect better occupational analysis.

Compared to the continuing titles, the new ones proportionately include far more involving repetitiveness, no discretion, or both, and far fewer dealing with people, involving directing, or emergencies (see tables MS–33 to MS–38). In short, the new titles, which include relatively few professionals but many technicians, show temperamental trends, the reverse of those shown by the continuing titles. In general, the temperaments needed by new titles show an overall drop in skill levels; those needed by the continuing titles, an increase.

TABLE MS–28. NET CHANGE IN TEMPERAMENTS OF REPETITIVENESS, VARIATION, AND NO DISCRETION, CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Repetitiveness and no discretion	0	0	1	2.2	+1
Repetitiveness	1	2.2	0	0	−1
No discretion	4	8.7	0	0	−4
Variation and no discretion	0	0	1	2.2	+1
Variation	5	10.8	32	69.6	+27
All others	36	78.3	12	26.1	−24
Total [1]	46	100.0	46	100.0	0

[1] Percentages may not total 100 percent because of rounding.

TABLE MS–29. NET CHANGE IN TEMPERAMENT OF DEALING WITH PEOPLE, CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Dealing with people	29	63.0	39	84.8	+10
All others	17	37.0	7	15.2	−10
Total	46	100.0	46	100.0	0

TABLE MS–30. NET CHANGE IN TEMPERAMENT OF DIRECTING, CONTROLLING, AND PLANNING, CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Directing, controlling, and planning	6	13.0	12	26.1	+6
All others	40	87.0	34	73.9	−6
Total	46	100.0	46	100.0	0

TABLE MS–31. NET CHANGE IN TEMPERAMENT OF INFLUENCING PEOPLE, CONTINUING OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Influencing people	29	63.0	38	82.6	+9
All others	17	37.0	8	17.4	−9
Total	46	100.0	46	100.0	0

Table MS–32. Net Change in Temperament of Emergencies, Continuing Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Emergencies	2	4.3	2	4.3	0
All others	44	95.7	44	95.7	0
Total	46	100.0	46	100.0	0

Table MS–33. Current Temperaments of Precision and Evaluation, Continuing and New Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Precision and evaluation, using both judgmental and quantitative information	2	1.8	0	0	2	1.3
Precision and evaluation, using either judgmental or quantitative information	40	36.0	10	25.0	50	33.1
Evaluation using both judgmental and quantitative information	4	3.6	1	2.5	5	3.3
Evaluation, using either judgmental or quantitative information	24	21.6	3	7.5	27	17.9
Precision	14	12.6	12	30.0	26	17.2
All others	27	24.3	14	35.0	41	27.2
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

Table MS–34. Current Temperaments of Repetitiveness, Variation, and No Discretion, Continuing and New Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Continuing titles		New titles		All current 3 titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Repetitiveness and no discretion	4	3.6	5	12.5	9	6.0
Repetitiveness	1	.9	8	20.0	9	6.0
No discretion	4	3.6	1	2.5	5	3.3
Variation and no discretion	6	5.4	1	2.5	7	4.6
Variation	60	54.1	19	47.5	79	52.3
All others	36	32.4	6	15.0	42	27.8
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

Table MS–35. Current Temperament of Dealing With People, Continuing and New Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Dealing with people	40	36.0	7	17.5	47	31.1
All others	71	64.0	33	82.5	104	68.9
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

Table MS–36. Current Temperament of Directing, Controlling, and Planning, Continuing and New Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Directing, controlling, and planning	35	31.5	5	12.5	40	26.5
All others	76	68.5	35	87.5	111	73.5
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

Table MS–37. Current Temperament of Influencing People, Continuing and New Occupational Titles in Medical Services by Number of Titles

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Influencing people	3	2.7	1	2.5	4	2.7
All others	108	97.3	39	97.5	147	97.3
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

Worker Functions

Almost half of all titles currently deal with data, a third with people, and a fifth with things, either alone or more likely in conjunction with other worker functions (see table MS–39). Precision working and manipulating are the most important functions involving things; compiling and coordinating are the most important involving data; and serving and mentoring, the most important involving people.

The new titles include a smaller percentage of high-skilled and a larger percentage of medium-skilled occupations, in contrast with continuing titles (see table MS–40). Moreover, the new titles are much more likely to be concerned with things and to involve precision-working and manipulating activities than with people and to involve mentoring or instructing. Where data functions are involved, the new titles are more likely to include compiling and less likely to involve coordinating (see table MS–39). The new titles appear to lean towards the manual and technical, while continuing titles tend more towards the professional and administrative. The present distribution of worker functions is in keeping with the earlier findings about aptitudes and temperaments, showing considerable differences between continuing and new titles.

TABLE MS–38. CURRENT TEMPERAMENT OF EMERGENCIES, CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Emergencies	7	6.3	1	2.5	8	5.3
All others	104	93.7	39	97.5	143	94.7
Total [1]	111	100.0	40	100.0	151	100.0

[1] Totals do not add to 119 continuing and 41 new titles because temperaments were not given for all titles.

TABLE MS–39. SELECTED-WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES BY NUMBER OF TITLES

Selected worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Things functions:						
Handling	7	3.1	2	3.3	9	3.1
Feeding-off bearing	0	0	0	0	0	0
Tending	1	.4	0	0	1	.3
Manipulating	8	3.5	8	13.1	16	5.5
Operating-controlling	1	.4	1	1.6	2	.7
Driving-controlling	1	.4	0	0	1	.3
Precision-working	20	8.7	12	19.7	32	11.0
Setting up	1	.4	1	1.6	2	.7
Total things functions	39	17.0	24	39.3	63	21.7
Data functions:						
Comparing	8	3.5	4	6.6	12	4.1
Copying	1	.4	0	0	1	.3
Computing	0	0	0	0	0	0
Compiling	27	11.8	15	24.6	42	14.5
Analyzing	6	2.6	4	6.6	10	3.4
Coordinating	64	27.9	4	6.6	68	23.4
Synthesizing	1	.4	0	0	1	.3
Total data functions	107	46.7	27	44.3	134	46.2
People functions:						
Serving	18	7.9	2	3.3	20	6.9
Speaking-signaling	10	4.4	2	3.3	12	4.1
Persuading	0	0	0	0	0	0
Diverting	0	0	0	0	0	0
Supervising	4	1.7	0	0	4	1.4
Instructing	6	2.6	4	6.6	10	3.4
Negotiating	10	4.4	2	3.3	12	4.1
Mentoring	35	15.3	0	0	35	12.1
Total people functions	83	36.2	10	16.4	93	32.1
Total	229	100.0	61	100.0	290	100.0

TABLE MS–40. SUMMARY OF SKILL LEVELS OF WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN MEDICAL SERVICES

Skill level	Continuing titles		New titles	
	Abilities number	Percent	Abilities number	Percent
Low	16	13.9	7	17.5
Medium	20	17.4	17	42.5
High	79	68.7	16	40.0
Total [1]	115	100.0	40	100.0

[1] Totals are less than the 119 continuing and the 41 new titles in other tables because of incomplete coding of titles by worker function.

Changes in Occupational Content

A comparison of the past and present descriptions of the 119 continuing titles shows few with meaningful changes in tasks or responsibilities. Nearly all with such changes were professional titles, some of which showed increases in aptitudinal requirements and changes in temperaments.

The descriptions of 59 titles (nearly half of all the 119 continuing titles) were unchanged; those of another 28 contained additional optional duties, but these were either elaborations of existing duties or seemed to be included to take account of minor differences in job content.[2] Fifteen of the decriptions contained 1 or 2 additional nonoptional tasks, but again these seemed primarily elaborations, not changes.

Of the 17 remaining titles (14 percent), 3 involved new equipment; 4, minor changes in procedures or processes; 2, both new equipment and minor changes; 3, major changes in tasks and responsibilities; and 5, a net reduction in duties.

All but 2 of the 12 that did not involve reduced duties were professional titles already requiring the maximum education and training, superior mental abilities, spatial comprehension, form perception, motor coordination, finger dexterity, and manual dexterity. The other two were technicians, one needing above-average education and training; the other, above-average spatial comprehension, form perception, manual dexterity, and clerical perception.

Two sets of educational, training, and aptitudinal requirements were available for 8 of the 12 titles. Only one of the technicians showed an increase in educational requirements. However, all but 1 of the other 11 titles already needed the maximum educational development; their requirements could not increase any further. At least five of the eight with two sets of data needed more form perception, eye-hand-foot coordination, and manual dexterity; and three needed more numerical ability. On the other hand, five also required less motor coordination and color discrimination. Changes in occupational content may have been responsible for these changes in educational and aptitudinal requirements, particularly since a number are similar to those experienced by all continuing titles.

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[2] For example, a dental hygienist now charts tooth decay for diagnosis by a dentist; a therapist prepares charge slips for use of equipment and special services and records the cost of materials; a medical technician administers X-ray therapy under supervision of a radiologist; another therapist requisitions equipment and supplies and maintains his tools in good working condition.

Two of the five titles with eliminated duties were professional; one each was technical, clerical, and service. The professional and technician titles already required above average education, training and mental abilities. One also needed above-average form perception, spatial comprehension, and finger dexterity. It is doubtful that the elimination of duties reduced skill levels of the professional and technical titles, although it may have narrowed work content of all five.

There also were changes in the temperaments of the 17 titles with meaningful changes in content. The most common change was the addition of precision working to the temperaments already needed, but it is unlikely that this reflected an actual change in work requirements, since all the affected titles were professional.

To conclude, most titles seemed basically the same, and on balance skill levels of continuing titles have not changed much, if at all. However, this stability may have reflected the insensitivity of the descriptions to subtle changes in required knowledge and techniques. More impressionistically, there was some indication of more paperwork required of professionals and technicians (as evidenced by the increase in the amount of clerical perception needed), and of greater specialization among technicians.

Conclusions

The evidence is mixed regarding changes in skill levels in medical services. On balance, there has been some rise in the educational requirements of continuing titles, particularly those already needing considerable amounts. In contrast, the educational and training requirements of new titles tend to be lower than those of continuing titles. Changes in aptitudes and temperaments also suggest a gain in skill by continuing titles but a comparative decline by new titles. The worker-functions profile confirms these findings. Nevertheless, changes in the occupational content of continuing titles were few and of little consequence for skill requirements. One generalization seems warranted. The skill level of titles at the top of the skill hierarchy seems to have increased; in contrast, the average skill level of new titles seems to have fallen relative to the entire occupational structure, partly because there are so few new professional titles.

Banking

Educational and Training Requirements

Banking includes a variety of occupational groups, both clerical and nonclerical, with some peculiar to the industry and others not. Nonclerical occupations include professionals, technicians, managers, supervisors, sales people, and even some manual and service workers. The only other industry studied that has a comparable amount of occupational diversity is medical services.

A large majority of the occupations (70 percent) are in the two middle educational ranges, that is, either the third or fourth level, a reflection of the many clerical titles (see tables B-1 and B-2). However, nearly 40 percent of all titles are at the third level, roughly the equivalent of a high school education but not necessarily a diploma. Another 20 percent require at least a fifth level of education, a reflection of the professional, technical, and managerial titles in the industry.

Clerical occupations not connected with the use of office machines are divided nearly evenly between those requiring a third and a fourth level of education. In contrast, clerical occupations that involve the operation of office machines, excepting typewriters, are concentrated at the second and third levels. Supervisors are at the fourth and fifth; managerial personnel, including security traders and salesmen, at the fifth level and to a lesser extent the sixth; and professionals are almost exclusively at the sixth or top level. There are too few technical titles to generalize about their educational requirements. The level of education corresponds closely with the level of the occupation.

The amount of vocational preparation needed also depends on the occupational group. Almost all the professionals need from 4 to 10 years; about half the managers need the same, with the remainder evenly divided on either side, from 2 to 4 years, or over 10. Nearly all clerical titles not connected with the use of office machines are distributed between 1 month and 1 year, but two-thirds need less than 6 months.[1] In contrast, four-fifths of the clericals who operate office machines, excepting typewriters, need less than 6 months, and over half need less than 3. The training needs of clerical supervisors range from 3 months to as high as 10 years, but nearly two-thirds need no more than 2 years and nearly half a year or less.

The 111 continuing titles with 2 sets of worker traits (about 57 percent of all continuing titles) have had only a modest gain in training requirements, but a substantial gain in educational (see tables B-4 to B-6). The major change in education was the decline in the number of titles at the second level (less than high school) and the increase in those at the fourth level (at least a high school diploma). There also was a drop in the number at the third level and a rise in those at the fifth and sixth. It is questionable whether this rise in educational requirements is entirely justified on the basis of changes in work requirements.

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[1] However, a small proportion (17 percent) need at least a year and as much as 4 years, and one title needs even more.

The changes in vocational requirements were complex, even though the overall net movement was quite small. There was a drop in the number of titles needing up to 3 months as well as from 1 to 2 years, but a rise in those needing anywhere from 3 to 12 months on the one hand, and from 2 to 10 years on the other.

In contrast to continuing titles, new titles show a net gain in training but not in educational requirements (see tables B-1 to B-3). New titles on the average seem to require just about as much education as continuing. Close to half in both groups need no more than a third level of education. The educational needs of the new titles seem to parallel the rise in those of the continuing.

The differences in the vocational requirements of the new and continuing titles are chiefly at the lower levels. The same proportions (roughly 70 percent) of both groups of titles need no more than a year of training. However, comparatively fewer of the new than the continuing titles need only 1 to 3 months, and comparatively more need anywhere from 3 to 12 months; however, the same proportions of both groups need up to a month. The slightly longer training needs of the new in comparison to continuing titles suggest at most a limited increase in skill requirements.

Differences in occupational composition help explain the differences in educational and training requirements of new and continuing titles. The new titles include a significantly larger proportion of office machine operators—one-third as compared to just 15 percent of the continuing titles. In addition, four more new titles are related to or derived from the use of office machines. A total of 18 of the 42 new titles thus are directly or indirectly associated with office equipment, and of the 18, 8 involve data processing equipment or functions.

The 12 operators of machines other than data processing require no more than a third level of education or (with 1 exception) over 6 months' training, and half need no more than 30 days. In contrast, the educational and training requirements of the two operators of electronic data processing equipment are somewhat greater than those of operators of conventional machines. The former need either a fourth or fifth level of education and either 3 to 6, or 6 to 12 months' training. Three of the six other titles linked to electronic equipment are supervisory, managerial, and professional, and require fairly high levels of education and training.

Thus, a disproportionately large number of new titles involve the use of office equipment and frequently electronic data processing equipment. It is these that account for the slightly higher training requirements of the new titles compared to those of the continuing titles, and to the maintenance of the same educational levels.

In contrast to the number of new titles, there were only five obsolete titles. Two had required only moderate amounts of education (a third level) and very little training (up to 30 days). A third had required less of both.

The continuing titles with increases in educational requirements are nearly all clerical, and include a disproportionately large number that originally required a second level of education, and a disproportionately small number that originally required a fourth level. Similarly, continuing titles with increases in vocational preparation are nearly all clerical, and include a disproportionately large number that orginally required up to 30 days' training and a disproportionately small number that originally required from 6 to 12 months.

These titles, however, are not necessarily at the bottom of the white-collar occupational hierarchy. To some degree, their educational upgrading appears to correct rankings that seem to have been too low. Also all clerical titles now tend to need at least a third or fourth level of education. Perhaps the completion of a certain amount of formal

TABLE B-1. CURRENT EDUCATIONAL AND TRAINING REQUIREMENTS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

GED-SVP level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1-1	1	0.5	0	0	1	0.4
2-1	1	.5	1	2.4	2	.9
2-2	5	2.6	4	9.5	9	3.8
2-3	4	2.1	0	0	4	1.7
2-4	1	.5	0	0	1	.4
3-2	8	4.1	1	2.4	9	3.8
3-3	30	15.5	2	4.8	32	13.6
3-4	24	12.4	10	23.8	34	14.5
3-5	14	7.3	3	7.1	17	7.2
4-3	8	4.1	0	0	8	3.4
4-4	13	6.7	1	2.4	14	6.0
4-5	19	9.8	8	19.0	27	11.5
4-6	8	4.1	2	4.8	10	4.3
4-7	10	5.2	2	4.8	12	5.1
4-8	2	1.0	1	2.4	3	1.3
5-4	0	0	1	2.4	1	.4
5-5	5	2.6	0	0	5	2.1
5-6	2	1.0	0	0	2	.9
5-7	9	4.7	3	7.1	12	5.1
5-8	12	6.2	0	0	12	5.1
5-9	2	1.0	1	2.4	3	1.3
6-7	2	1.0	0	0	2	.9
6-8	13	6.7	2	4.8	15	6.4
Total [1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total to 100 percent because of rounding.

Table B–2. Current Educational Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

GED level	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	1	0.5	0	0	1	0.4
2	11	5.7	5	11.9	16	6.8
3	76	39.4	16	38.1	92	39.1
4	60	31.1	14	33.3	74	31.5
5	30	15.5	5	11.9	35	14.9
6	18	7.8	2	4.8	17	7.3
Total	193	100.0	42	100.0	235	100.0

Table B–3. Current Training Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

SVP levels	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	2	1.0	1	2.4	3	1.3
2	13	6.7	5	11.9	18	7.7
3	42	21.8	2	4.8	44	18.7
4	38	19.7	12	28.5	50	21.2
5	38	19.7	11	26.2	49	20.9
6	10	5.2	2	4.8	12	5.1
7	21	10.9	4	9.5	25	10.6
8	27	14.0	4	9.5	31	13.2
9	2	1.0	1	2.4	3	1.3
Total	193	100.0	42	100.0	235	100.0

Table B–4. Net Change in Educational and Training Requirements of Continuing Occupational Titles in Banking by Number of Titles

GED–SVP levels	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1–1	0	0	1	0.9	+1
2–1	0	0	1	.9	+1
2–2	12	10.8	3	2.7	−9
2–3	7	6.3	2	1.8	−5
2–4	1	.9	0	0	−1
3–2	2	1.8	6	5.4	+4
3–3	20	18.0	21	18.9	+1
3–4	21	18.9	18	16.2	−3
3–5	11	9.9	6	5.4	−5
3–6	3	2.7	0	0	−3
4–2	2	1.8	0	0	−2
4–3	3	2.7	5	4.5	+2
4–4	4	3.6	9	8.1	+5
4–5	6	5.4	9	8.1	+3
4–6	3	2.7	3	2.7	0
4–7	2	1.8	7	6.3	+5
4–8	1	.9	1	.9	0
5–5	0	0	5	4.5	+5
5–6	0	0	0	0	0
5–7	4	3.6	3	2.7	−1
5–8	5	4.5	5	4.5	0
6–7	1	.9	1	.9	0
6–8	3	2.7	5	4.5	+2
Total [1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–5. Net Change in Educational Requirements of Continuing Occupational Titles in Banking by Number of Titles

GED level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	1	0.9	+1
2	20	18.0	6	5.4	−14
3	57	51.4	51	46.0	−6
4	21	18.9	34	30.6	+13
5	9	8.1	13	11.7	+4
6	4	3.6	6	5.4	+2
Total	111	100.0	111	100.0	0

Table B–6. Net Change in Training Requirements of Continuing Occupational Titles in Banking by Number of Titles

SVP level	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	2	1.8	+2
2	16	14.4	9	8.1	−7
3	30	27.0	28	25.3	−2
4	26	23.5	27	24.3	+1
5	17	15.3	20	18.0	+3
6	6	5.4	3	2.7	−3
7	7	6.3	11	9.9	+4
8	9	8.1	11	9.9	+2
Total	111	100.0	111	100.0	0

schooling serves as evidence of a satisfactory level of literacy or deportment.

The increase in the educational and training requirements of the continuing titles and the increase in the training requirements of the new titles, suggest that, on balance, skill requirements in banking have increased. The increase in training requirements indicated by the new titles is attributable largely to occupations associated with electronic data processing equipment.

Aptitudinal Requirements

A sizable number of titles in banking require exceptional abilities in only three aptitudes: General learning ability, numerical ability, and clerical perception (see tables B–7 to B–16). One-quarter of the titles require above average ability in the first, 30 percent in the second, and 45 percent in the third. No more than 10 percent of the titles need superior amounts of the remaining aptitudes.

About four-fifths of the titles requiring superior clerical perception are clerical. However, four-fifths needing superior learning and verbal ability are professional, technical, managerial, and supervisory. Most of the rest represent tellers, cashiers, bookkeepers, and others dealing with accounting records or systems. About half the titles needing above average numerical ability also are professional, technical, managerial, and supervisory; the other half are clerical (but included are only five office machine operators). With some exceptions, clerical titles with superior numerical ability require no more than average learning and verbal ability. The exceptions are those representing tellers, cashiers, secretaries, and stenographers.

Both the new and continuing titles need much the same amounts of numerical ability and clerical perception. The similarity stops there, however (see tables B-7 to B-16). Compared to the continuing titles, the new include more needing less learning and verbal ability, and many more needing less color discrimination. On the other hand, the new titles include a substantially larger number needing more motor coordination and manual dexterity, and a moderately large number that need more finger dexterity, spatial comprehension, and form perception.

A comparison of the past and present aptitudes of the 111 continuing titles with two sets of worker traits shows almost no change in the numbers requiring various amounts of numerical ability; but it does show moderate gains in those needing more clerical perception, and large gains in those needing more motor coordination and spatial comprehension (see tables B-17 to B-26). In the other direction, there were modest increases in those needing less learning ability and moderate increases in those needing less form perception, finger dexterity, and color discrimination. Ambiguous changes occurred in verbal ability and manual dexterity, and almost none in eye-hand-foot coordination.

The aptitudinal needs of the new titles and the present requirements of the continuing ones agree with respect to spatial comprehension, motor coordination, color discrimination, eye-hand-foot coordination, and general learning ability, but not with respect to clerical perception, form perception, numerical ability, finger dexterity, verbal ability, and manual ability. However, the two sets of aptitudes show directly opposite results only with respect to form perception and finger dexterity.[2] Irrespective of these differences, fewer than 10 percent of all titles need superior spatial comprehension, form perception, finger dexterity, manual dexterity, motor coordination, or eye-hand-foot coordination.

To summarize, new titles compared with continuing titles seem to require somewhat less learning and verbal ability and considerably less color discrimination; but they require moderately more spatial comprehension, form perception, and finger dexterity, and much more manual dexterity and motor coordination. Relatively more new titles needed average or better than average spatial comprehension and above average form perception, while relatively more needed average finger dexterity, manual dexterity, and motor coordination at the expense of those needing less than average amounts.

Examining the changes from past to present, the continuing titles needed somewhat less learning ability, form perception, finger dexterity, and color discrimination but moderately more clerical perception, and considerably more motor coordination and spatial comprehension. The results were uncertain regarding verbal ability and manual dexterity, and not especially meaningful regarding color discrimination. There were moderate gains in the number of titles needing superior clerical perception, and large gains in those needing average motor coordination. In contrast, there were modest declines in the number needing superior learning ability, and moderate declines in those needing average or better form perception, some color discrimination, and at least average finger dexterity. There was no change in numerical ability or in eye-hand-foot coordination.

The aptitudinal needs of the new titles and the changes in those of the continuing titles are difficult to reconcile, but their few shared features indicate an increase in skill requirements. The new titles suggest a gain in certain physical if not mental requirements. The continuing titles point, but less certainly, to a similar increase, and more definitely to one in clerical perception as well. There are conflicts, however, regarding at least one perceptual aptitude and lack of mutual support regarding clerical perception, numerical ability, and dexterity. Further, a sizable number of titles need better than average capabilities in only one of the aptitudes in which greater ability is now required. The increase in skill levels thus could not have been large.

TABLE B-7. CURRENT COMPOSITE INTELLIGENCE REQUIREMENTS (GVN) OF CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Current GVN [1]	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
111	4	2.1	2	4.8	6	2.6
112	10	5.2	0	0	10	4.2
113	3	1.6	0	0	3	1.3
121	6	3.1	0	0	6	2.6
122	1	.5	0	0	1	.4
212	1	.5	0	0	1	.4
213	1	.5	0	0	1	.4
221	0	0	1	2.4	1	.4
222	9	4.7	3	7.1	12	5.1
223	11	5.7	2	4.8	13	5.5
224	2	1.0	0	0	2	.9
232	1	.5	0	0	1	.4
233	1	.5	0	0	1	.4
323	1	.5	1	2.4	2	.9
332	25	13.0	5	11.9	30	12.8
333	68	35.2	14	33.3	82	34.9
334	34	17.6	7	16.6	41	17.4
335	3	1.6	0	0	3	1.3
343	1	.5	2	4.8	3	1.3
344	2	1.0	0	0	2	.9
444	8	4.2	5	11.9	13	5.5
445	1	.5	0	0	1	.4
Total [2]	193	100.0	42	100.0	235	100.0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.

[2] Percentages may not total 100 percent because of rounding.

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[2] The other instances of lack of agreement are one set showing no change or an ambiguous one, while the other shows a specific shift. There is compatibility if not exact correspondence with respect to changes in these aptitudes.

Table B–8. Current General Learning Ability (G) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	24	12.4	2	4.8	26	11.1
2	16	13.5	6	14.3	32	13.6
3	133	68.9	29	69.0	162	68.9
4	10	5.2	5	11.9	15	6.4
5	0	0	0	0	0	0
Total	193	100.0	42	100.0	235	100.0

Table B–9. Current Verbal Ability (V) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	19	9.8	2	4.8	21	8.9
2	30	15.6	7	16.7	37	15.7
3	132	68.4	26	61.9	158	67.3
4	12	6.2	7	16.7	19	8.1
5	0	0	0	0	0	0
Total [1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total 100 percent because of rounding.

Table B–10. Current Numerical Ability (N) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	10	5.2	3	7.2	13	5.5
2	47	24.3	8	19.0	55	23.4
3	86	44.6	19	45.2	105	44.7
4	48	24.9	12	28.6	60	25.5
5	2	1.0	0	0	2	.9
Total	193	100.0	42	100.0	235	100.0

Table B–11. Current Clerical Perception (Q) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	6	3.1	0	0	6	2.6
2	81	42.0	19	45.2	100	42.6
3	81	42.0	18	42.9	99	42.1
4	23	11.9	5	11.9	28	11.9
5	2	1.0	0	0	2	.8
Total	193	100.0	42	100.0	235	100.0

Table B–12. Current Coordination Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Motor coordination (K)					
1	0	0	0	0	0	0
2	17	8.8	3	7.1	20	8.5
3	75	38.9	22	52.4	97	41.3
4	94	48.7	14	33.3	108	46.0
5	7	3.6	3	7.1	10	4.2
Total [1]	193	100.0	42	100.0	235	100.0
	b. Eye-hand-foot coordination (E)					
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	10	5.2	3	7.1	13	5.5
5	183	94.8	39	92.9	222	94.5
Total [1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total to 100 percent because of rounding.

Table B–13. Current Dexterity Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
	a. Manual dexterity (M)					
1	0	0	0	0	0	0
2	4	2.1	0	0	4	1.7
3	86	44.6	26	61.9	112	47.7
4	88	45.6	11	26.2	99	42.1
5	15	7.7	5	11.9	20	8.5
Total	193	100.0	42	100.0	235	100.0
	b. Finger dexterity (F)					
1	0	0	0	0	0	0
2	15	7.8	3	7.1	18	7.7
3	74	38.3	20	47.6	94	40.0
4	92	47.7	17	40.5	109	46.4
5	12	6.2	2	4.8	14	5.9
Total	193	100.0	42	100.0	235	100.0

Table B–14. Current Spatial Comprehension (S) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	1	2.4	1	0.4
2	5	2.6	2	4.8	7	3.0
3	30	15.5	10	23.8	40	17.0
4	139	72.0	23	54.8	162	68.9
5	19	9.9	6	14.2	25	10.7
Total	193	100.0	42	100.0	235	100.0

Table B–15. Current Form Perception (P) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	11	5.7	7	16.7	18	7.7
3	69	35.8	15	35.7	84	35.7
4	105	54.4	15	35.7	120	51.1
5	8	4.1	5	11.9	13	5.5
Total	193	100.0	42	100.0	235	100.0

Table B–16. Current Color Discrimination (C) Requirements of Continuing and New Occupational Titles in Banking by Number of Titles

Aptitude ratings	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
1	0	0	0	0	0	0
2	3	1.6	0	0	3	1.3
3	35	18.1	1	2.4	36	15.3
4	155	80.3	13	31.0	168	71.5
5	0	0	28	66.6	28	11.9
Total	193	100.0	42	100.0	235	100.0

Table B–17. Net Changes in Composite Intelligence Requirements (GVN) of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings[1]	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
111	2	1.8	2	1.8	0
112	1	.9	3	2.7	+2
113	3	2.7	1	.9	−2
121	4	3.6	4	3.6	0
122	3	2.7	0	0	−3
212	1	.9	1	.9	0
213	0	0	1	.9	+1
222	3	2.7	4	3.6	+1
223	5	4.5	4	3.6	−1
224	1	.9	2	1.8	+1
232	2	1.8	0	0	−2
233	2	1.8	1	.9	−1
242	1	.9	0	0	−1
323	2	1.8	1	.9	−1
324	2	1.8	0	0	−2
332	12	10.8	16	14.4	+4
333	30	27.0	37	33.3	+7
334	25	22.5	26	23.4	+1
335	2	1.8	1	.9	−1
343	3	2.7	0	0	−3
344	2	1.8	0	0	−2
433	1	.9	1	.9	0
434	1	.9	0	0	−1
444	1	.9	6	5.4	+5
445	2	1.8	0	0	−2
Total[2]	111	100.0	111	100.0	0

[1] The first number is the general learning ability (G) rating; the second, verbal ability (V) rating; and the third, numerical ability (N) rating.
[2] Percentages may not total 100 percent because of rounding.

Table B–18. Net Change in General Learning Ability (G) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	13	11.7	10	9.0	−3
2	15	13.5	13	11.7	−2
3	78	70.3	81	73.0	+3
4	5	4.5	7	6.3	+2
5	0	0	0	0	0
Total	111	100.0	111	100.0	0

Table B–19. Net Change in Verbal Ability (V) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	7	6.3	8	7.2	+1
2	20	18.0	15	13.5	−5
3	75	67.6	82	73.9	+7
4	9	8.1	6	5.4	−3
5	0	0	0	0	0
Total	111	100.0	111	100.0	0

Table B–20. Net Change in Numerical Ability (N) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	6	5.4	6	5.4	0
2	23	20.7	24	21.6	+1
3	46	41.4	46	41.4	0
4	32	28.8	34	30.6	+2
5	4	3.6	1	.9	−3
Total[1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–21. Net Change in Clerical Perception (Q) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	4	3.6	+4
2	47	42.3	51	45.9	+4
3	46	41.4	42	37.8	−4
4	18	16.2	13	11.7	−5
5	0	0	1	.9	+1
Total[1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–22. Net Change in Coordination Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Motor coordination (K)				
1	0	0	0	0	0
2	16	14.4	13	11.7	−3
3	32	28.8	46	41.4	+14
4	58	52.3	46	41.4	−12
5	5	4.5	6	5.4	+1
Total[1]	111	100.0	111	100.0	0
	b. Eye-hand-foot coordination (E)				
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	2	1.8	5	4.5	+3
5	109	98.2	106	95.5	−3
Total[1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–23. Net Change in Dexterity Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
	a. Manual dexterity (M)				
1	0	0	0	0	0
2	3	2.7	2	1.8	−1
3	50	45.0	54	48.7	+4
4	56	50.5	46	41.4	−10
5	2	1.8	9	8.1	+7
Total[1]	111	100.0	111	100.0	0
	b. Finger dexterity (F)				
1	0	0	0	0	0
2	10	9.0	13	11.7	+3
3	44	39.6	42	37.8	−2
4	55	49.6	48	43.2	−7
5	2	1.8	8	7.2	+6
Total[1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–24. Net Change in Spatial Comprehension (S) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	1	.9	2	1.8	+1
3	11	9.9	16	14.4	+5
4	67	60.4	82	73.9	+15
5	32	28.8	11	9.9	−21
Total	111	100.0	111	100.0	0

Table B–25. Net Change in Form Perception (P) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	9	8.1	8	7.2	−1
3	48	43.2	40	36.0	−8
4	48	43.2	58	52.3	+10
5	6	5.4	5	4.5	−1
Total[1]	111	100.0	111	100.0	0

[1] Percentages may not total 100 percent because of rounding.

Table B–26. Net Change in Color Discrimination (C) Requirements of Continuing Occupational Titles in Banking by Number of Titles

Aptitude ratings	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
1	0	0	0	0	0
2	1	.9	0	0	−1
3	1	.9	2	1.8	+1
4	27	24.3	20	18.0	−7
5	82	73.9	89	80.2	+7
Total	111	100.0	111	100.0	0

Temperamental Requirements

Two-thirds of the titles are repetitive in nature, half allow no discretion, and nearly 30 percent combine both characteristics.[3] Half of the last group involve the operation of office equipment, including typewriters; most of the other office equipment titles have varied duties. At least one-quarter of all titles currently use evaluation alone or also require precision (see tables B–27 to B–31). The large majority (about three-quarters) of these are professional, technical, managerial, or supervisory, while only one-quarter are clerical. Thirty percent of all titles require precision alone or combined with other temperaments, and nearly all of these are clerical. Titles involving the use of office machines, including typewriters, typically are repetitive, limited in discretion, or both, but they often (62 percent) demand precision. Finally, about one-third of the titles deal with people. A majority of these are managerial and supervisory, but a large minority (two-fifths) are clerical, including secretarial duties, providing information, receiving clients, receiving customers, and handling money as well (e.g., tellers).

In short, many titles that use judgment, require precision, or involve interpersonal relationships are professional, technical, managerial, or supervisory. However, a significant proportion of clerical titles have similar characteristics; those that involve the use of office machines generally do not.

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[3] Selected rather than composite temperaments are examined because the latter are too numerous to reveal patterns.

There is little difference between the temperaments currently needed by continuing and new titles, except that a slightly larger proportion of new titles involve evaluation, variation, and directing; and slightly fewer involve dealing with or influencing people. In general, however, these differences are too small to be meaningful (see tables B-27 to B-31).

Similarly there are few net changes in the temperaments required of the 111 continuing titles with two sets of worker traits[4] (see tables B-32 to B-35). On a net basis, somewhat more of these continuing titles now require either evaluation or precision, and involve dealing with or influencing people or varied duties. On the other hand, twice as many titles, on a net basis, have become repetitive as have become varied. Moreover, there was a net drop in the number of titles that combine both evaluation and precision, half offsetting the net gain in titles involving either one or the other. There are few other changes in temperaments. Only one such change of the continuing titles corresponds with the shifts indicated by the new titles. However, both the continuing and the new titles indicate relatively few net changes and little or no change in skill requirements.

The main change in the temperaments required by titles involving the use of office equipment is the addition of repetitiveness and discretion, as well as precision. The main change in the requirements of managerial and supervisory titles is the addition of evaluation. There are no other occupational patterns. Better occupational description and analysis, not changes in work requirements, may have been responsible for at least some of the changed temperaments of the managerial and supervisory titles. Accordingly, overall net changes in temperaments may be even less significant than they first seem.

TABLE B-27. SELECTED CURRENT TEMPERAMENTS OF EVALUATION, PRECISION, AND INTERPRETATION, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Evaluation and precision	11	5.7	2	4.8	13	5.5
Evaluation and interpretation	1	.5	0	0	1	.4
Evaluation	34	17.6	10	23.8	44	18.7
Precision	52	26.9	11	26.2	63	26.8
Other	95	49.2	19	45.2	114	48.5
Total[1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE B-28. SELECTED CURRENT TEMPERAMENTS OF REPETITIVENESS AND VARIATION, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Variation	62	32.1	15	35.7	77	32.8
Repetitiveness	99	51.3	21	50.0	120	51.1
Other	32	16.6	6	14.3	38	16.1
Total	193	100.0	42	100.0	235	100.0

TABLE B-29. SELECTED CURRENT TEMPERAMENT OF NO DISCRETION, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
No discretion	107	55.4	22	52.4	129	54.9
Other	86	44.6	20	47.6	106	45.1
Total	193	100.0	42	100.0	235	100.0

TABLE B-30. SELECTED CURRENT TEMPERAMENT OF DIRECTING, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Directing	23	11.9	7	16.7	30	12.8
Other	170	88.1	35	83.3	205	87.2
Total	193	100.0	42	100.0	235	100.0

TABLE B-31. SELECTED CURRENT TEMPERAMENTS OF DEALING WITH PEOPLE AND INFLUENCING PEOPLE, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Dealing with people	68	35.2	10	23.8	78	33.2
Influencing people	8	4.1	0	0	8	3.4
Other	117	60.6	32	76.2	149	63.4
Total[2]	193	100.0	42	100.0	235	100.0

[2] Percentages may not total 100 percent because of rounding.

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[4] However, the number of net changes substantially understates the total number of titles with changed temperaments. Seventy of the 111 continuing titles have such changes, nearly 85 percent of which are clerical.

TABLE B-32. NET CHANGE IN SELECTED TEMPERAMENTS OF EVALUATION, PRECISION, AND INTERPRETATION, CONTINUING OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Evaluation and precision	7	6.3	5	4.5	−2
Evaluation and interpretation	0	0	1	.9	+1
Evaluation	11	9.9	16	14.4	+5
Precision	34	30.6	38	34.2	+4
All Others	59	53.2	51	46.0	−8
Total	111	100.0	111	100.0	0

TABLE B-33. NET CHANGE IN SELECTED TEMPERAMENTS OF REPETITIVENESS AND VARIATION, CONTINUING OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Variation	19	17.1	27	24.3	+8
Repetitiveness	66	59.5	81	73.0	+15
All others	26	23.4	3	2.7	−23
Total	111	100.0	111	100.0	0

TABLE B-34. NET CHANGE IN SELECTED TEMPERAMENT OF NO DISCRETION, CONTINUING OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
No discretion	34	30.6	36	32.4	+2
All others	77	69.4	75	67.6	−2
Total	111	100.0	111	100.0	0

TABLE B-35. NET CHANGE IN SELECTED TEMPERAMENTS OF DEALING WITH PEOPLE AND INFLUENCING PEOPLE, CONTINUING OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected temperaments	Former		Current		Net abilities change
	Abilities number	Percent	Abilities number	Percent	
Dealing with people	20	18.0	28	25.2	+8
Influencing people	3	2.7	5	4.5	+2
All others	88	79.3	78	70.3	−10
Total	111	100.0	111	100.0	0

Worker Functions

The many combinations of worker functions in table B-36 can be broken down into their components for easier analysis (see tables B-37 to B-40).

TABLE B-36. WORKER FUNCTIONS OF CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Primarily involving things:						
Handling	2	1.0	0	0	2	0.9
Tending	7	3.6	5	11.9	12	5.1
Manipulating	2	1.0	0	0	2	.9
Operating-controlling	4	2.1	0	0	4	1.7
Driving-controlling	1	.5	0	0	1	.4
Primarily involving data:						
Comparing	4	2.1	0	0	4	1.7
Copying	11	5.7	0	0	11	4.7
Computing	12	6.2	0	0	12	5.1
Compiling	48	24.9	11	26.2	59	25.1
Analyzing	4	2.1	2	4.8	6	2.6
Coordinating	7	3.6	1	2.4	8	3.4
Synthesizing	1	.5	1	2.4	2	.9
Primarily involving people:						
Serving	2	1.0	0	0	2	.9
Speaking-signaling	1	.5	0	0	1	.4
Primarily involving things and data:						
Handling and comparing	4	2.1	2	4.8	6	2.6
Handling and copying	1	.5	1	2.4	2	.9
Handling and compiling	3	1.6	2	4.8	5	2.3
Feeding-offbearing and comparing	0	0	1	2.4	1	.4
Tending and comparing	1	.5	0	0	1	.4
Operating-controlling and copying	3	1.6	4	9.5	7	3.0
Operating-controlling and computing	0	0	1	2.4	1	.4
Operating-controlling and compiling	1	.5	3	7.1	4	1.7
Precision-working and comparing	1	.5	0	0	1	.4
Precision-working and analyzing	2	1.0	0	0	2	.9
Primarily involving things and people:						
Handling and speaking-signaling	1	.5	0	0	1	.4
Operating-controlling and speaking-signaling	1	.5	0	0	1	.4
Primarily involving data and people:						
Comparing and speaking-signaling	1	.5	0	0	1	.4
Copying and taking instructions-helping	1	.5	0	0	1	.4
Copying and serving	1	.5	0	0	1	.4
Copying and speaking-signaling	2	1.0	0	0	2	.9
Computing and persuading	2	1.0	0	0	2	.9
Compiling and taking instructions-helping	2	1.0	0	0	2	.9
Compiling and speaking-signaling	17	8.8	2	4.8	19	8.1
Compiling and persuading	1	.5	0	0	1	.4
Analyzing and speaking-signaling	5	2.6	0	0	5	2.3
Analyzing and negotiating	1	.5	0	0	1	.4
Analyzing and persuading	1	.5	0	0	1	.4
Analyzing and instructing	1	.5	0	0	1	.4
Coordinating and speaking-signaling	1	.5	1	2.4	2	.9
Coordinating and supervising	16	8.3	5	11.9	21	8.9
Coordinating and negotiating	13	6.7	0	0	13	5.5
Coordinating and mentoring	1	.5	0	0	1	.4
Synthesizing and supervising	1	.5	0	0	1	.4
Synthesizing and negotiating	1	.5	0	0	1	.4
Primarily involving things, data, and people:						
Setting up, coordinating, and supervising	1	.5	0	0	1	.4
Total [1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total 100 percent because of rounding.

The functions of nearly four-fifths of the titles primarily involve either data or data and people (see table B-37). The functions of most of the relatively few remaining titles are divided evenly between those chiefly concerned with things or things and data; that is, with the use of office equipment for the most part. A large proportion (nearly two-thirds) of the titles dealing with data involve low-skilled compiling, and about half as many cases involve high-skilled coordinating functions (see tables B-38 to B-41). Most of the titles dealing with things involve simple handling and tending activities, and, in about three-fifths as many cases, medium-skilled operating-controlling activities. Those concerned with people mostly involve elementary speaking-signaling or high-skilled supervising and negotiating functions. There thus seems to be some polarization with respect to data, things, and people activities. A large proportion of titles in each category either are low skilled or medium and high skilled.

TABLE B-37. SUMMARY OF THINGS, DATA, AND PEOPLE WORKER FUNCTIONS, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Worker functions dealing primarily with—	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Things	16	8.3	5	11.9	21	8.9
Data	87	45.1	15	35.7	102	43.4
People	3	1.6	0	0	3	1.3
Things and data	16	8.3	14	33.3	30	12.8
Things and people	2	1.0	0	0	2	.9
Data and people	68	35.2	8	19.0	76	32.3
Things, data, and people	1	.5	0	0	1	.4
Total	193	100.0	42	99.9	235	100.0

TABLE B-38. SELECTED WORKER THING FUNCTIONS, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Handling	11	31.4	5	26.3	16	29.6
Feeding-offbearing	0	0	1	5.3	1	1.9
Tending	8	22.9	5	26.3	13	24.1
Manipulating	2	5.7	0	0	2	3.7
Operating-controlling	9	25.7	8	42.1	17	31.5
Driving-controlling	1	2.9	0	0	1	1.9
Precision-working	3	8.6	0	0	3	5.6
Setting up	1	2.9	0	0	1	1.9
Total[1]	35	100.0	19	100.0	54	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE B-39. SELECTED WORKER DATA FUNCTIONS, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Comparing	14	8.1	3	8.1	17	8.2
Copying	16	9.6	5	13.5	21	10.1
Computing	14	8.1	1	2.7	15	7.2
Compiling	72	42.1	18	48.6	90	43.3
Analyzing	14	8.1	2	5.4	16	7.8
Coordinating	38	22.2	7	18.9	45	21.6
Synthesizing	3	1.8	1	2.7	4	1.9
Total[1]	171	100.0	37	100.0	208	100.0

[1] Percentages may not total 100 percent because of rounding.

The new titles, in contrast to the continuing, included relatively fewer concerned chiefly with data or with data and people, and relatively more concerned with things or with things and data (see table B-37). This difference reflects the large number of new titles that involve the use of office machines, especially electronic data processing equipment. Whether or not in conjunction with some other function or functions, the new titles also include relatively more copying and compiling functions among those concerned with data operating-controlling functions and among those concerned with things, and more supervising functions among those concerned with people (see tables B-38 to B-40).

TABLE B-40. SELECTED WORKER PEOPLE FUNCTIONS, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Selected worker functions	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Taking-instruction-helping	3	4.1	0	0	3	3.7
Serving	3	4.1	0	0	3	3.7
Speaking-signaling	29	39.7	3	37.5	32	39.5
Persuading	4	5.5	0	0	4	4.9
Diverting	0	0	0	0	0	0
Supervising	17	23.3	5	62.5	22	27.2
Instructing	1	1.4	0	0	1	1.2
Negotiating	15	20.5	0	0	15	18.5
Mentoring	1	1.4	0	0	1	1.2
Total[1]	73	100.0	8	100.0	81	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE B-41. SUMMARY OF SKILL GROUPS OF WORKER FUNCTIONS, CONTINUING AND NEW OCCUPATIONAL TITLES IN BANKING, BY NUMBER OF TITLES

Skill groups	Continuing titles		New titles		All current titles	
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
Low skilled	39	20.2	9	21.4	48	20.4
Medium skilled	97	50.3	23	54.8	120	51.0
High skilled	57	29.5	10	23.8	67	28.5
Total[1]	193	100.0	42	100.0	235	100.0

[1] Percentages may not total 100 percent because of rounding.

There is no indication that proportionately more new than continuing titles are high skilled. At best, there seems to be relatively a few less low-skilled and a few more medium-skilled titles among the new ones.

Changes in Occupational Content

The definitions of nearly two-thirds of the 193 continuing titles changed in some way, with a resulting increase in the skill levels of over one-third of them. However, in most cases the increase is not substantial (see tables B–42 and B–43). There are only a few clear-cut relationships between these apparent changes in skill and changes in education, training, aptitudes, and temperaments.

The definitions of about one-third of the titles did not change; the definitions of another 28 percent changed but did not seem to alter overall skill requirements. The most common change in the latter was an increase in the number of duties, including optional ones, which were not more complex and which required no greater skill than already needed. These additional duties may have broadened the content of the titles affected and possibly may have increased their complexity; however, it is just as likely that duties were added to make the descriptions comprehensive enough to cover variations in the content of the same jobs in different establishments. In contrast, only a handful of titles were narrowed by a net elimination of duties. Titles whose skill levels did not change included a disproportionately large number involving the use of office equipment, including the typewriter, and to some extent a disproportionate number of managerial, supervisory, professional, and technical titles.

Comparatively few skill variations involved greater mechanization or changes in operating methods associated with changes in equipment. No more than 30 of the 193 continuing titles (16 percent of the total) were so affected, and only 10 (6 percent) involved the use of more mechanized or more automatic equipment, typically simple in nature. Forty-five percent of the equipment changes seemed to raise skill requirements (none substantially); very few led to decreases.

In contrast to the continuing titles, over two-fifths of the 42 new titles involved the use of office machines, and over one-fifth, the use of electronic data processing equipment. Nearly a quarter of the 235 new and continuing titles involved more mechanization, but less than 10 percent involved automated equipment. There was more use of simple office equipment and automated equipment, but neither development was common.

Two of the five obsolete titles involved the operation of simple office machines, but none was high skilled, and at least two were low skilled. In contrast, one-fifth of the 42 new titles were managerial, supervisory, professional, or technical. The new titles thus included a higher proportion of high skilled and machine-related titles than the obsolete ones.

Two other types of changes in content also were evident. One was the broadening of responsibilities and duties of many managerial, supervisory, professional, and technical titles. However, it was difficult to determine if this broadening was the result of better occupational description and analysis or of actual changes in work content. The second was the greater elaboration of the duties of many clerical titles without any apparent change in actual content.

These descriptive changes hampered efforts to decide whether changes in definitions actually involved changes in overall skill requirements. The tendency was to err in favor of increases in skill in the absence of evidence that added duties were not new. Even so, no more than 11 percent of the 193 continuing titles seemed to have marked increases in skill, and these tended to exclude titles involving the use of office machines. The chief point, however, is that any net shift in skill was upward. Skill levels seemed to fall in only six titles and substantially in the case of two.

Efforts to relate skill level changes to changes in education, training, and aptitudes were only moderately successful. Compared to titles with no changes in skill levels, those with skill increases[5] included a larger proportion that needed more training, clerical perception, and spatial comprehension.[6] At the same time, a larger proportion required less form perception, manual dexterity, eye-hand-foot coordination, and color discrimination. These decreases in requirements, however, were concentrated among aptitudes not typical of clerical titles.

Compared to titles without changes in skill level, the five with declines in skills surprisingly included a larger proportion needing more education, verbal ability, and color discrimination, as well as a larger proportion needing less training, form perception, and finger dexterity.

Increases in educational needs seemed to be independent of changes in work content. Many titles with no change in skill levels and with lower skill levels needed more education. Moreover, the proportion of titles with increases in skills that needed more education were no different from those with no changes in skills needing more education.

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[5] With two sets of worker traits. All titles compared here and in the following paragraphs have two sets of such information.

[6] The measure used was the relative net change in the number of titles, arranged by type of skill level change, whose educational, training, aptitudinal, or temperamental requirements changed. The net number was derived by subtracting the number of titles with decreases in a given requirement from the number with increases. A percentage increase indicated that more titles had an increase than a decrease in the amount needed of the particular requirement; a percentage decrease indicated that more titles had a decrease than an increase.

For example, of the 42 titles with increases in skill levels and whose former and current educational and training requirements could be compared, 10 had no change in either educational or training requirements, 4 had a drop in 1 requirement uncompensated by a rise in the other, and 8 had an increase in one offset by a drop in the other. In short, the educational or training needs either moved in the wrong direction or not at all for 22 of the 42. Educational requirements rose for the remaining 20, but remained relatively low (at the third level) for 10. Similarly, educational requirements of 30 of the 57 continuing titles with increases in skill levels were still relatively low (at the second and third levels). Further, 14 of the 67 required no more than 6 months' vocational preparation.

There was also a relationship between changes in skills and temperaments. Compared to continuing titles with no changes in skill levels, titles with skill increases were more likely now to involve evaluation and varied or repetitive duties. Titles with declines in skills were less likely now to involve varied duties and were more likely to involve repetitive duties. Other changes in the temperaments of titles with reduced skills were in the wrong direction, however. They were more likely currently to need evaluation and precision and less likely to lack discretion. In general, the amount of temperamental change was less than one might expect from actual changes in skill levels as distinguished from changes due to better occupational analysis.

Changes in occupational content indicated a rise in skills and in educational, training, aptitudinal, and temperamental requirements. The increase in skill was at most moderate, while the increases in needed worker traits, especially educational development, were not always associated with actual changes in work content. Changes in equipment or working methods occurred but were not numerous, and they were accompanied typically by increases in skill levels or no changes in them, rather than by decreases.

Conclusions

The evidence points to some rise in the skill requirements of occupations in banking, particularly clerical. Increases in skill are indicated by the increase in the educational and training needs of continuing titles and in the training needs of new ones, by changes in occupational content, and to some extent by changes in aptitudinal requirements. New titles associated with electronic data processing equipment seem responsible for some of the increase in training requirements and hence in skill levels. Finally, worker functions show a modest rise in the number of medium skilled titles and a decrease in the number of low skilled ones. The only negative evidence comes from changes in temperament requirements, which suggest no change in skills. On balance, few temperaments actually changed and few net shifts occurred in those that did. The weight of the evidence, however, is on the side of a rise in the overall level of skill.

TABLE B-42. NUMBER OF CONTINUING OCCUPATIONAL TITLES IN BANKING WITH INCREASES, DECREASES, AND NO CHANGE IN SKILLS BY NUMBER OF TITLES WITH ADDED AND ELIMINATED TASKS

Change in skill level	Number of tasks added or eliminated				All current titles	
	A few		Many			
	Abilities number	Percent	Abilities number	Percent	Abilities number	Percent
No change in duties or definition					66	34.2
Changes in duties:						
No change in skill level	34	61.8	20	27.8	54	28.0
Increases in skill level	18	32.7	49	68.1	67	34.7
Decline in skill level	3	5.5	3	4.2	6	3.1
Total [1]	55	100.0	72	100.0	193	100.0

[1] Percentages may not total 100 percent because of rounding.

TABLE B-43. AMOUNT OF INCREASED SKILL, CONTINUING OCCUPATIONAL TITLES IN BANKING BY NUMBER OF TITLES

Amount of skill increase	Number of titles	As percentages of all—	
		Titles with skill increases (N=67)	Continuing titles (N=193)
Negligible	6	9.0	3.1
Modest	19	28.4	9.8
Moderate	28	41.8	14.5
Substantial	14	20.9	7.3
Total [1]	67	100.0	34.7

[1] Percentages may not add to their respective totals because of rounding.

Summary and Conclusions of the Industry Studies

We have examined occupations in five industries with respect to changes in worker abilities and occupational content which were indicative of changes in skill requirements. Taken together, the industries included all major occupational groups, although some industries showed more occupational diversity than others.

The worker abilities were given by so-called worker traits. These were the education, training, aptitudes, and temperaments needed for successful performance in an occupation. The occupational content was given by occupational definitions and by so-called worker functions which ranked occupations by the complexity of their tasks.

The changes in abilities and content were determined by comparing (1) today's worker traits and occupational definitions with those of the late 1940's for the same occupations, and (2) current traits and definitions of occupations added since the late 1940's with those of occupations in existence both then and now.

The overall or net change in the skill requirements of occupations in these industries was remarkably small, despite the 15 years covered. One industry on balance had an increase, one a possible decline, but in each case the shift was modest. Moreover, substantive changes in occupational content were not common, and the number of obsolete occupations was few. However, the small net change in skill levels was the product of numerous offsetting changes in the various abilities needed for individual occupations in an industry. There was considerable change in occupational requirements and content, but on balance it was either inconsequential or inconclusive with respect to overall skill levels.

CHANGING CHARACTER OF HUMAN WORK UNDER THE IMPACT OF TECHNOLOGICAL CHANGE

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Changing Character of Human Work Under the Impact of Technological Change

Introduction

Raymond Aron has written: "The essence of a scientific society is change . . . . Adjustment and social integration have come to require the acceptance of instability." If adaptability were substituted for "instability," these words would define the theme of this report which focuses on the impact of change stemming from science and technology on the character and climate of human work in the United States.

Increasingly, the new man-work and man-machine relationships are being recognized as matters of public interest. At most levels they have important behavioral as well as psychological effects. The most obvious negative ones are lowered efficiency both in quantity and quality of product or service, and at certain critical times, slowdowns or strikes. Therefore, this report deals more specifically with work as seen through the eyes of the worker and as experienced by him on the job, whether this be in an office or factory. It also relates the individual's personal work experience to the public interest.

The focus is strictly upon men at work and does not deal with problems of displacement or retraining as such. Emphasis is placed upon those sectors of the work force referred to by the census as "operatives" (still the largest single category of the gainfully employed—18.4 percent according to the President's Manpower Report of 1965) and "craftsmen, foremen, and kindred workers" (12.8 percent of the total).

An important shift occurred in the American economy in the early 1950's, when it changed from one which for 30 years had emphasized mass-production technologies and the jobs appropriate to them to an economy which is emphasizing automatic techniques and the jobs appropriate to such innovations. This era, still in its early stages, is notable for very large research and development expenditures and for rapidly growing employment in the service industries and in government agencies.

Automation and other technical innovations do not necessarily worsen conditions of work in the modern world; they present society with critical new problems and also new opportunities. Therefore, this report will be concerned with pinpointing the most important of these problems and with identifying as many solutions or ameliorative measures as possible.

I. Background and Genesis of Modern Work Environments

"The true significance of the Industrial Revolution," wrote a member of the 1929 Committee on Recent Economic Changes, of which Herbert Clark Hoover was chairman, "was that it carried the transfer of skill to such a degree as to make the worker an adjunct to the tool whereas, formerly the tool was an adjunct to the skill of the worker."

When in 1789 Whitney set up a workshop in New Haven to manufacture muskets for the U.S. Army, he took a giant step in the transfer of skills by making, with relatively unskilled labor, interchangeable parts on precision machines. The idea was revolutionary and considered impractical by nearly everyone. Even 2 years later the Army's skepticism forced Whitney to make a special trip to Washington to demonstrate that the 10 muskets he brought with him could operate with interchangeable parts. Had this innovation not been accepted, and had two primary precision tools, the lathe and the milling machine not been invented, metals products could never have been mass produced.

Lathes, milling machines, and other machine tools have, of course, been steadily improved since Whitney's time. According to the *American Machinist*, the machine tools of 1957 were 54 percent more productive per man-hour than those made 10 years earlier, and between 1940 and 1950 efficiency increased by 40 percent. But until as late as 1955 all machine tools still required the services of highly skilled craftsmen, such as tool and die makers, setup men, skilled machinists, and experienced machine operators. The advent of numerical control in 1955 has resulted in many of these skills being transferred to automatically controlled machines which do the job more quickly, more accurately, and with greater flexibility. Thus, numerical control may be said to represent the most recent step in the long history of transfer of skills, and its consequences promise to be far-reaching for the whole economy.

Although mass production in America before World War II was made possible by the "American system of interchangeable parts manufacture," two other elements were indispensable before it achieved its full potential. The first, organizational in character, may also be regarded as another facet of the transfer of skills—the minute division of labor into simple, repetitive tasks. The principle is, of course, as old as Adam Smith, but it could only have reached full fruition under the special pressures of a mass market. The second was the chain conveyor. When the Ford chassis assembly was put into operation in 1913 after 9 months of experimentation, the time to complete an automobile chassis dropped from 12 hours and 28 minutes to 93 minutes.

Growth of the transfer of skills through ever more efficient and productive machines together with the assemblyline gave American industrial production a new and distinctive character between the two world wars. In fact, the tremendous growth in the volume of consumer goods, from automobiles to radios, resulted primarily from these developments. Together they succeeded in transforming not only the physical aspects of our civilization, but much of the human work which supported it.

As has happened so often in history, the technological demands of war, this time World War II, forced the scientific, engineering, and industrial world to break through to still newer ground.

> During World War II great numbers of men were brought together from different fields to pool their abilities for the design of weapons and instruments. As a result, *the specialists of engineering and science found themselves talking to one another for the first time in generations.* Mechanical engineers exploited techniques of circuit theory borrowed from the communications engineers; aeronautical engineers extended the use of electrical concepts of measurement and of mathematical presentation; mathematicians working with engineers and experimental scientists discovered entirely unsuspected practical uses for forgotten theorems . . . .[1] [Emphasis supplied.]

Scientists and engineers had been employed by industry and government for many years, but only after World War II, reinforced 10 years later by the cold war and Korean conflict did their efforts come to be regarded as a new "industry," that of research and development, or R&D. This industry's work force comprises an estimated million to a million and a half scientists, engineers, and technicians.[2]

As a result of the new status of research and development, both industry and government are continually assigning research contracts which lead to new knowledge and new products. It was, for example, from such a contract with the Air Force that engineers at M.I.T. developed the first numerically controlled machine tools which became commercially available in 1955.

Immediately after World War II, new transfers of skills and the growth of automatic controls began to make themselves felt in the work environment. These were summed up in general thinking as "automation," which rests on a wide variety of scientific breakthroughs and new technologies. As is now all but common knowledge, the term itself was first applied in 19[illegible]6 in the automobile industry to the integration of machine tools with one another on conveyors which moved engine blocks through hundreds of cutting, drilling, and grinding operations with the use of little or no manual labor. Later, much inspection also was performed automatically. In 1927, 3 weeks was allowed for the machining of a cylinder block. This time was gradually reduced over the years until with the advent of "transfer machines" the time per block is roughly 15 minutes. Workers monitor the machines.

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[1] Gordon S. Brown and Donald P. Campbell, "Control Systems," in *Automatic Control*, by the editors of *Scientific American*, Simon and Schuster, New York, 1955, pp. 31–32.

[2] See, for example, "An Exploratory Study of the Structure and Dynamics of the R&D Industry," by Albert Shapero, Richard P. Howell, and James R. Tombaugh, Stanford Research Institute, Menlo Park, Calif., June 1964. The terms "industry" and "work force" are taken from this study.

Other early installations with automatic or semiautomatic features were made in the steel industry with the introduction and refinement of continuous rolling and continuous pipe mills. As a logical development, continuous casting machines for both steel and aluminum are now being introduced. But long before these developments, the oil and chemical industries had begun to install automatic controls which year by year have become technically more and more sophisticated and extensive.

Although no wholly automatic factory exists in the United States today, the use of automatic machinery, computers, and servomechanisms is growing steadily in many industries. How fast this is occurring and what are its effects on productivity and unemployment remain much disputed questions. So, too, is the nature of automation itself. Is it really something new, or is it, in essence, no different from the many technological revolutions of the past?

Statisticians, both government and private, point out that productivity in manufacturing has increased as a whole by only 2.5 percent a year over the last 20 years; therefore, claims that technological change has been accelerating are much exaggerated. Although the overall figures cannot be denied, the conclusions drawn from them by those who minimize the impact of technological change can be as dangerously mistaken as their opponents' conclusions who claim that an overnight transformation of the economy is taking place—soon it will be run entirely by pushbuttons and computers!

A difficulty on both sides of the argument has been the attempt to prove or disprove that technological change and its impact on the labor force have been the chief cause of high unemployment in the last decade. Careful studies by the Bureau of Labor Statistics and the Council of Economic Advisers as well as a recent analysis by Robert M. Solow of M.I.T.[3] have established that to date, at least, our overall unemployment problem cannot be laid at the door of accelerated technological change. Leaving aside, however, for present purposes, the controversy over structural unemployment versus insufficient aggregate demand, turn from these overall statistics to what is actually occurring in important sectors of the economy. The speed of technological change now and for the decade ahead promises to challenge all the social ingenuity and wisdom we can muster.

Take, for example, the recent findings of so careful and conservative a student of the progress of automation in this country as James Bright. He writes on the acceleration of automation considered not generally but selectively.

> When my study of 13 highly automatic factories was published in 1958, the occasion prompted a review of their condition. I was startled to find that every one of these plants, which had been the last word in technological progress in 1955, was now surpassed. These (and other automation concepts studied in 1954–55) represented expenditures of almost a quarter of a billion dollars. In 3 years the production advances bought by this enormous investment had been overtaken. While all but one plant was still a good production system, *none* of them was any longer the lowest cost producer. None of them would have been duplicated by their managements as proper 1958 designs. Technological change had invalidated a large amount of their technique and equipment.[4]

To be sure, as Daniel Bell has remarked in a recent article, "*For example* is no proof." But on the other hand it is well to remember the statistician who drowned while crossing a river because reliable fellow statisticians had assured him the average depth of the river was only 3 feet.

Technological change does not proceed at an even pace; that is its essence. The steel industry is installing highly mechanized, 1965-model basic oxygen furnaces; yet a wheelbarrow, technologically circa 3000 B.C., is used for adding ingredients to some of these furnaces. Similar disparities, if somewhat less extreme, can also be found in many other industries. Although productivity for the economy as a whole (including agriculture) has increased on the average of 3 percent a year between 1947 and 1963, and at approximately the same rate (3.1 percent) between 1957 and 1963, such overall statistics give no indication of the large increase in certain industries where technological innovation has moved at a high speed and whose gains far outstrip the average. Productivity in coal mining rose 6.6 percent per production worker man-hour between 1947 and 1962, and 7.7 percent between 1957 and 1962. On railroads, output per production worker man-hour rose 4.9 percent in the 1947–62 period, and 6.1 between 1957 and 1962. Other industries whose productivity surpassed the national average include iron mining, 8.6 percent; copper mining, 4.4 percent; tobacco manufacture, 6.1 percent; petroleum refining, 7.2 percent; tires and inner tubes, 6.1 percent; gas and electric utilities 7.4 percent.[5] Overall averages have clearly been kept down by the slow movers; witness, for example, the relatively low productivity gains registered in trade, finance, insurance, and real estate. Even within these categories, however, the productivity of selected companies has been raised by the introduction of computers and new methods of materials handling.

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[3] Robert M. Solow, "The Nature and Sources of Unemployment in the United States," Wicksell Lectures 1964, Almquist & Wicksell, Stockholm.

[4] James R. Bright, *Research Development and Technological Innovation*, Richard D. Irwin, Inc., Homewood, Ill., 1964, p. v.

Statistics on past technological change as reflected in productivity are of less importance for the purposes of this report than what may be expected in the foreseeable future. The best single source for such information is the well-known study "Technological Trends in 36 Major American Industries," made in 1964 by the Office of Productivity and Technological Developments of the Bureau of Labor Statistics for the President's Committee on Labor-Management Policy. Among industries included are mining, manufacturing, construction, trade, public utilities, transportation, insurance, banking and government; together they account for almost half of total nonfarm employment. The technological innovations discussed are, the study notes, "in an early stage of commercial usage—i.e., the period after introduction on the market but before widespread adoption. Inventions and discoveries still in the 'drawing-board' stage and considered not likely to have as much impact over the next decade as those already tested are not generally discussed."

Not a single one of these 36 industries but has important innovations underway. The study foresees some degree of increased automatic machinery and equipment and/or automatic instrumentation and control, including new uses of numerical control and computers in every one of the 36 industries except trucking; even in trucking, semiautomated freight stations are being introduced. This does not mean that every kind of automation is anticipated for every industry or for every establishment within each industry. However, in addition to those technological innovations grouped under the broad category of "automation," industries are being transformed by new materials, methods and processes, or simply by new and improved machinery.

The old, of course, will continue beside the new. This is perhaps nowhere more vividly illustrated than in the automobile industry, where large-scale introduction of numerical control in the tooling-up process promises to revolutionize the whole timetable of model changeover, and yet the assembly line is expected to continue relatively unchanged.

Whether or not automation represents something new and different in industrial history is, of course, another question. Brown and Campbell, pioneers in the field of automatic controls and servomechanisms, say that it does:

> In an automatically controlled system, as in the human organism, the whole is far greater than its parts. The instruments, circuits, tubes and servomechanisms are but the hardware of the grand design . . . there is a growing recognition among engineers and scientists that they cannot deal with control systems part by part, but must design each system as a unitary whole. Automatic control as we wish to speak of it here means the synthesis of product, process, plant and instruments. This implies designing the plant for control as much as designing controls for the plant. System engineering, therefore, calls for the pooled resources and efforts of professionals in many fields—mathematicians, scientists, engineers, and administrators. It must integrate information and art from many branches of technology. . . .[6]

In investigating the impact of automation and other technologies on work, the conventional formula of wages, hours, and working conditions is still commonly used. However, to analyze work environments in the modern world, several other measurements or work dimensions are strategic for determining both productivity and satisfaction.

A series of eight work dimensions are suggested here as an analytic tool for different industries and technologies. These dimensions are specifically designed to highlight the characteristics of work as affected or determined by the job's technological component, that is, the machines or other "hardware" connected with a man's work, as distinguished from organizational structure. They are:

1. Knowledge and skill requirement.
2. Pacing or rate of performance.
3. Degree of repetitiveness or variety.
4. Relation to the total product or process. (This includes how much of a particular product or process the individual works on as well as his overall relation to the total operation of his plant or unit.)
5. Relationships with people as individuals or groups. (This includes the frequency of interactions and whether these are functionally required by the work or are discretionary.)
6. Style of supervision and managerial controls, whether administrative or technological.
7. Degree of worker's autonomy in determining work methods.
8. Relation of work to personal development, both on the job and with respect to transfers and promotions.

"Degree of responsibility" demanded by the job is not named specifically because this may be deduced from the other dimensions.

The importance of these and other dimensions over and above "wages and hours" is being increasingly recognized by both management and unions. Their relevance not only to immediate satisfaction or dissatisfaction on the job but to personal growth at work and frustration or fulfillment in a working life will be discussed. One of the most interesting comments on this relatively new area of systematic investigation has come from a trade union leader:

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[5] *Indexes of Output per Man-Hour, Selected Industries, 1939 and 1947–62,* Bureau of Labor Statistics, Sept. 1964.

[6] Brown & Campbell, *op. cit.*, pp. 31–32. (The author is fundamentally in agreement with this statement, but would add to the professionals listed life scientists with their knowledge of the bodies and minds of individuals at work.)

> If unions are going to survive and grow in this coming period, they have to break with their old patterns. First of all, they have to break with their pattern of not thinking about work, the nature of work, their relationship to work, and what they can do about work.[7]

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[7] Paul Jacobs, United Autoworkers Union, quoted by Turner and Lawrence, *Industrial Jobs and the Worker*, Harvard University, Graduate School of Business Administration, Boston, 1965.

II. Case Studies of Different Technologies

Assemblyline Technology—Automobile

The impact of technology on these work dimensions can be profitably weighed by examining the classical example of mass-production manufacturing on automobile assemblylines.

Ample research findings for the industry not only demonstrate the close relation between technology and attitudes and behavior of workers, but much of these data are also applicable to assemblyline technologies in other industries. And although extreme examples of unfavorable work environments due to technology are confined to a relatively small number of final assemblyline workers, it is here that behavioral effects have the most serious social consequences, for the individual, the industry, and the economy as a whole. The record shows that the prolongation of both legal and illegal walkouts in automobile factories is often due to "local working conditions" in assembly plants. Here the impact of technology on job dimensions is greatest. In the nationwide General Motors' strike in the fall of 1964, of the 28 plants that remained on strike after the official settlement, 22 were assembly plants. Eight others, although accepting the terms of the general settlement, declared they would remain idle until their companion assembly plants had satisfactorily settled "local issues." These 30 assembly plants accounted for 77 percent of General Motors' automaking capacity. Significantly, all the plants except two which agreed to the official settlement were plants not involved in final assembly.

The first four dimensions—knowledge and skill requirements, pacing and rate of performance, degree of repetitiveness or variety, and relation to the total product or process—are clearly related and flow from "principles" of mass production.[8]

Typical jobs on the "main line," or moving conveyer, serve to illustrate these dimensions and their interrelationship. Consider the job of the automotive worker who installs toeplates:

> I put in the two different toeplates that cover the holes where the brake and clutch pedals are. I am inside the car and have to be down on the seat to do my work. On one kind of car I put in the shift lever while another man puts in the toeplates.[9]

While doing his job this man rides along in the car performing two operations, and must complete the job in 2 minutes, or else he will be carried too far. He then returns to his station, climbs into another car, and begins all over again. Thus his pace is strictly governed by the moving line. Such a job is also highly repetitive. Only slight variety is introduced when the worker installs a shift lever instead of a toeplate on certain cars. The job demands very little skill and has a learning period of just 2 days. Although the worker gets in and out of cars 20 or 30 times an hour, his expenditure of physical energy on the actual operation is slight.

A somewhat similar situation can also apply to jobs not on a moving belt. For example, a blower-defroster assembler who works off the main line describes his job as follows:

> I work at a bench on blower-defrosters. The blowers come in two parts. I take one part and attach the blower motor to it. I then connect the fan to the motor shaft. Then I take the other half of the air pipe and put two parts together with 14 screws. I test the motor to see if it works, and if it does, I put in the 15th screw which grounds it to the pipe. The materials are brought to me and put in a pile by a stock chaser. After I finish, I put each assembled blower on one of six shelves.

Here pace is only indirectly determined by the main line, since the worker has some choice of pace in keeping his shelves stocked with a supply of blower-defrosters. There is little variety since he performs only three operations. However, a slight variation is introduced through differences in models. His job operations require a minimum of skill: "I learned it in a couple of hours, though it took me about a week to get up speed."

For both these jobs skill requirements are clearly low, the jobs are strictly paced and repetitive and only a small fraction of the product is worked on. These characteristics also appear to be required by the technology.

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[8] "Mass production is not merely quantity production for this may be had with none of the requisites of mass production. Nor is it merely machine production which also may exist without any resemblance to mass production. Mass production is the focusing upon a manufacturing project of the principles of power, accuracy, economy, system, continuity, speed and repetition . . . the keyword to mass production is simplicity. Three plain principles underlie it: (a) The planned, orderly, and continuous progression of the commodity through the shop; (b) the delivery of work instead of leaving it to the workman's initiative to find it; (c) an analysis of operations into their constituent parts. These are distinct but not separate steps; . . . All three fundamentals are involved in the original act of planning moving line production." Henry Ford, "Mass Production," *Encyclopedia Britannica*, 22d ed., vol. 15, pp. 38–40.

[9] Job descriptions given here come from interviews with actual job holders. But since details of assembly jobs vary from year to year, and change with the introduction of new models, the descriptions are cited only as generally typical of assembly work. They do not reproduce in detail any current job descriptions for any one company.

A good general description of the overall engineering design of an automobile assembly is given in the Department of Labor's occupational handbook:

> Final assembly is the process of putting together in sequence the individual parts of the subassemblies, with the completed vehicle rolling off the end of the line. Overhead wires feed electric power to nut tighteners, welding equipment, and other tools used by workers on the assemblyline. A conveyor carries the motor vehicles forward while men at work stations attach the necessary parts and subassemblies in proper sequence.
>
> Generally the assembly of a car starts with the frame which forms the foundation of the motor vehicle. All other parts and subassemblies are attached to it. Large and heavy subassemblies, such as the engine and the body, are lowered by hoists into position on the chassis as it comes down the line. The finishing accessories, such as bumpers, hubcaps, and floor mats, are added near the end of the line. Finally, the headlights are adjusted, the wheels are aligned, and gasoline is pumped into the fuel tank, and thus another new motor vehicle is driven off the line under its own power.[10]

Studies of final assemblyline work in a major automobile company by the Technology Project of Yale University found the average time cycle for jobs to be 3 minutes. As to learning time, a few hours to a week sufficed. Learning time for 65 percent of the force was less than a month. In one of the plants, 31.7 percent of the work force performed 1 operation to complete each job cycle; 12.8 percent, 2 operations; 22.8 percent, 3 to 5 operations; 16.1 percent, 5 to 10 operations; and 15.5 percent, 10 or more operations. For 1.1 percent, it was impossible to determine clearly the number of operations performed.

In examining the technological work environment which characterizes final assembly in the automobile industry, it is important to remember that the effects, in terms of strict pacing, repetitiveness, etc., are extreme. While skill demands and learning time are considerably higher for other sections of the auto industry, nearly half of all automobile manufacturing workers in 1960 filled assembling, inspecting, materials handling, and other semiskilled jobs. Another fourth were employed as foremen, mechanics and repairmen, machinists, tool and die makers, and in other skilled occupations. Clerical workers were about a 10th of those employed, and the remainder worked in professional, technical, sales, and managerial occupations and as laborers and guards.[11]

If we were to ask whether automation has modified these findings, the answer would of necessity be yes and no. The "transfer machine," or "Detroit automation," has transformed the manufacture of engines, and in introducing numerical control for retooling, automobile manufacturers have linked automatic machine tools to perform a variety of operations. But final assembly itself, the classic example of mass-production technology, has not been substantially altered. The reason is simple: To automate an operation which involves fitting together some 10,000 separate parts would not be economically feasible.

The frequency and character of interpersonal relations on the assemblyline, the fifth dimension, are largely determined by mechanical factors, and for most workers are reduced to an occasional exchange of a few words with those nearest on the moving line. Noise, rapidity of the moving conveyors and the demands of the work itself for unremitting attention are the principal deterrents to verbal interaction. Furthermore, few jobs on an automobile assemblyline require a functional or team relationship. For the most part, workers are stationed serially along a moving conveyor, each quickly performing his own individual function which must be completed before the part moves to his neighbor. A certain quota of men along a certain length of the main line (or on subassembly lines or at benches) are assigned to a foreman. In a sense these men constitute separate work groups; however, they have little cohesiveness or sense of unity. Just as the pacing and repetitiveness of the work reduce to a minimum *horizontal* relations between workers, so they also limit vertical relations, i.e., interaction with foremen. And, not surprisingly, investigators report that dislike of rigid pacing and repetitiveness is greatly accented by correlative restrictions on interpersonal relationships of all kinds. The sense of constriction and pressure on the lines is also affected by the availability of relief men. For example, no worker is permitted to leave the line to go to the toilet until a relief man has been located to take his place. Accordingly, the worker speaks of himself as tied to the line.

Since the speed set for the line "supervises" the *pace* of work, and in fact determines the number of completed cars that come off the end of the line each hour, the sixth dimension, style of supervision, may be thought to be comparatively unimportant. But, nonetheless, the role of the foreman is of primary importance, and perhaps unexpectedly, a foreman actually can choose from a variety of styles of supervision. He may reinforce or amplify the coercion inherent in the pacing and repetitiveness of the job, or he may in a variety of ways lighten that pressure and humanize the job for his workers.[12]

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[10] U.S. Department of Labor, *Occupational Outlook Handbook*, 1959, p. 502.

[11] "Employment Outlook in Motor Vehicles Manufacturing," *Occupational Outlook Report Series*, Bureau of Labor Statistics, Bulletin No. 1375–101.

[12] For further expansion of these points see: Charles R. Walker, Robert H. Guest, and Arthur N. Turner, *The Foreman on the Assembly Line*, Harvard University Press, Cambridge, Mass., 1956.

The seventh dimension, degree of autonomy in determining work methods, has been skillfully eliminated as far as humanly possible by careful engineering calculation. Some latitude does creep back when there is a model change. Then work is reassigned; but before the final resubdivision of tasks has been completed, the individual may be permitted to perform more operations and work on a somewhat larger fraction of the final product.

The eighth dimension, relation of work to personal development both on the job and with respect to transfer and promotions, is easily the most important, and from the individual's standpoint embraces, in a sense, all the others. Whether they are blue-collar, white-collar, or administrative workers, people will commonly endure severe restrictions and hardships in their careers if the work itself is psychologically rewarding or if it is clearly a rung of the ladder leading to a satisfactory job future. Jobs in final assembly comparable to those outlined are neither.

After remarking on the inherent impersonalization of the moving conveyor, Robert Blauner has summarizing the lack of psychological rewards in final assembly work this way:

> The alienation of meaninglessness is further intensified by the workers' lack of a clear identification with a particular job. The division of labor is so extreme that most jobs are basically the same. In addition, because there are many lines operating at once, there are a number of men performing exactly the same tasks. One cannot, therefore, derive a sense of function as the left-front hubcap assembler. Fractionalized job assignments, cyclic rather than task-directed work rhythms, and the anonymous atmosphere of the large plants all dilute the sense of meaning, purpose, and function on the assembly line.[13]

As to the potential for a progressive work career through promotion or transfer, the wage floor in auto assemblylines is indeed high, but it is flat. Since nearly all jobs have been broken down into a relatively simple set of motions, little gradation in skills exists between a job in one section of the line and another. Translated in terms of wages, there is little spread between the lowest and highest job classes. In one plant, for example, Yale Technology Project investigators found that two-thirds of the workers in the two largest departments received exactly the same wage; the promotion ladder among production workers was virtually nonexistent. Robert Guest, commenting on the same point said:

> By applying principles of work rationalization, the industrial engineer, in the best interests of efficiency, had simplified the tasks so that differences in skill from one job to the next were all but eliminated. It was difficult for the average worker to move vertically through a series of distinct steps in promotion. In this connection, it should be added that over the years the union itself, through collective bargaining, had encouraged the trend toward uniform wage standards by raising minimum levels without increasing the relative amounts between job classes.
>
> From a careful examination of the actual work careers of over 200 workers we have found only a few who had experienced any substantial change in job classification during a period of from 12 to 15 years.[14]

As one might expect, individual workers reacted with varying degrees of intensity to the assemblyline technology. One worker disliked most of all the repetitiveness of the job; another, the pacing of the line; another, restriction of movement or of interaction; another, the lack of opportunity for advancement. A small minority appeared indifferent to any of these factors. On the positive side, the relatively high-wage rate for all jobs was the most commonly liked feature of assemblyline work. This was especially true for younger men. Many older workers with families felt they had wasted their lives in a skill-less occupation, but were now hesitant to leave and sacrifice seniority. Most of the work force pointed out that layoffs substantially reduced annual earnings.

Despite individual differences, overall attitudes were remarkedly consistent. The Yale Technology Project found that a majority of workers were satisfied with wages, but 9 out of 10 disliked intensely the pacing and repetitiveness of their jobs. The plant for which these findings were first reported was relatively new and many of the workers were fresh to factory work. In order to test their validity, investigators spent 2 years more in another study of a much older plant where workers had long seniority records in assembly work. The findings in the older plant were the same, with only minor differences, the most important being less satisfaction with the economic rewards.

For many methodological reasons, it is less satisfactory to measure worker attitudes than actual behavior. The technology project sought, therefore, to relate work dimensions to actual behavior. Some evidence in early studies of hourly wage earners made by the British Medical Council indicated that a correlation might exist between certain mass-production characteristics of industrial jobs and absentee and turnover records. A mass-production index was accordingly constructed for each worker's job, consisting of the following scalable factors: (1) Degree of repetitiveness; (2) degree of mechanical pacing; (3) skill as measured by length of learning time; (4) frequency of break in job routine; (5) frequency of social interaction; and (6) size of interacting group. This index was applied to each worker's job, and the resulting profiles were then correlated with company records of absenteeism and turnover.

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[13] Robert Blauner, *Alienation and Freedom: The Factory Worker and His Industry*, The University of Chicago Press, Chicago, 1964, p. 108.

[14] Guest, Robert H., "Men and Machines, An Assembly-Line Worker Looks at His Job." The Yale Technology Project, Yale University, New Haven, Conn., reprinted from *Personnel*, May 1955.

A statistically significant correlation was found to exist between absenteeism and mass-production characteristics. Men with highly repetitive jobs—conveyor paced and the like—were far more likely to take time off from work than those with other types of jobs. Quit records showed that twice as many workers left jobs with extreme mass production as with moderate mass-production characteristics. Both factors were reflected in higher costs of production.

The unfavorable impact of mass-production characteristics isolated and measured in the technology project studies has been confirmed by the substantial Kornhauser study, conducted over several years under a grant from the National Institute of Mental Health and recently made public:

> The outstanding finding is that mental health varies consistently with the level of jobs the men hold. When we compare the factory workers by occupational categories, the higher the occupation (in respect to skill and associated attributes of variety responsibility and pay) the better the mental health. Those in skilled jobs have highest mental-health scores, followed by the semiskilled and, lowest of all, the men in routine, repetitive types of work.[15]

Assemblyline Technology—Electronics Industry

All assembly technologies do not, of course, produce unfavorable worker reactions similar to those discussed above. For example, the reaction is quite different and far more favorable in a division of the same automobile company studied where small parts are assembled on a moving belt. Clearly one must ask under what conditions reactions are favorable, or what kind of assemblyline technology provides work dimensions that enhance rather than depress the morale and mental and physical health of workers.

A recent study of repetitive work in an assembly plant in the electronics industry suggests some answers.[16]

The study was set in a large assembly department of a manufacturer of high-quality electronic products. Operators were divided into teams of from three to six girls working either at benches, where the product was moved by hand from one assembler to her neighbor, or at small conveyors, which moved the parts. The typical job cycle for each team member was 1 minute or less. The final product was assembled by attaching 10 or more small and delicate parts, often under a magnifying glass, and the result was then inspected on the bench under a microscope. Samples of every team's output were subjected to a complex series of tests by a quality control department. Most operators worked under a group incentive plan that paid a uniform bonus to each member of the team for all products produced above a certain quality standard.

A large majority of the operators found the work rewarding. They did not complain of repetitiveness or of mechanical pressure from the moving conveyor. At an earlier stage of this study, a variety of interferences with this satisfactory situation had been reported; however, most had been eliminated by the time these findings were reported.

It was found that the assembly process can be organized to provide a form of psychological "traction" rather than the distraction or coercion characteristic of the automobile assembly line.[17] Thus, repetitive assembly work does not necessarily imply unfavorable work characteristics under conditions when (1) the product is attractive; (2) interpersonal relations are not excluded; (3) pride in an unusual kind of skill and quality is possible; and (4) the smooth pull of the process is not interrupted by excessive supervisory attention. All these conditions were fulfilled in the work environment of the electronics assemblyline studied.

Data on these two assemblyline technologies have been carefully examined and compared by Thomas M. Lodahl of Cornell. His approach, that of a quantitative industrial psychologist, throws added light on the impact on human beings of varying types of technology. Table 1 and a portion of Lodahl's findings are quoted from his study which was made in consultation with the author of this report. The data used for auto assembly were obtained from the previously mentioned Yale Technology Project study of the high-seniority plant, and those for electronics operators were from one of the electronics plants referred to above. Lodahl found more conflict and tension among the electronics operators than Turner and Miclette did, probably because Lodahl's data were obtained before many causes of tension were removed. Lodahl says:

> Table [1] gives the mean and standard deviations for the attitude ratings in the two technologies. Examining the assembly-line data first, it is clear that the greatest satisfaction for these men is satisfaction with pay and satisfaction with fellow workers. They are dissatisfied with supervision, the company, the union, and working conditions. Their intrinsic job satisfaction is low, even though they seem to feel remarkably little interference in getting work done. Tension and conflict generally seem at high-medium levels, not too surprising in view of the fact that all these men had at least 12 years of seniority. Other conflicts are high for these men; these conflicts ranged from anger at too little relief time, through general disgust with foremen's behavior, to outrage at being denied permission to visit the plant hospital. Involve-

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[15] *Mental Health and the Industrial Worker*, Arthur Kornhauser, John Wiley & Sons, Inc., New York, 1965. See especially pp. 260 ff.

[16] Arthur N. Turner and Amelia L. Miclette, "Sources of Satisfaction in Repetitive Work," *Occupational Psychology*, vol. 36, No. 4, October 1962, pp. 215–231.

[17] Cf. W. Baldamus, who fully develops these concepts in *Efficiency and Effort: An Analysis of Industrial Administration*, Tavistock Publications, London, 1961.

ment in the job is reasonably high; these men still seem to care how well they do on the job, even though product involvement is low and company involvement is lower still.

TABLE 1. MEAN AND STANDARD DEVIATIONS OF ATTITUDE MEASURES IN TWO ASSEMBLY TECHNOLOGIES

Attitude measure	Auto assembly workers		Electronics operators	
	N=50		N=29	
	Mean	Standard deviations	Mean	Standard deviations
Intrinsic job satisfaction	1.66	1.43	2.41	1.30
Satisfaction supervisor	1.40	1.34	2.50	1.42
Satisfaction fellow workers	2.76	.87	2.52	1.05
Satisfaction company	.68	.97	1.80	1.22
Satisfaction union	1.30	1.25	2.37	.90
Satisfaction work conditions	1.32	1.13	1.38	1.26
Satisfaction pay	3.02	.90	3.11	.76
Plans	1.60	.53	1.83	.47
Own performance	(1)	(1)	(1)	(1)
Difficulty	2.28	1.37	2.52	.94
Responsibility	(1)	(1)	(1)	(1)
Tension	2.50	1.37	3.34	1.56
Interferences	.96	1.34	3.38	1.55
Quality-quantity conflict	2.20	1.58	2.71	1.86
Other conflict	3.64	.59	4.04	.89
Status congruence	.48	.50	(2)	(2)
Feedback	5.41	2.24	4.59	2.81
Job involvement	2.39	1.45	3.33	1.44

[1] Not comparable scales.
[2] Not available.

The outlook of the women in electronics differs in important ways from the men on the assembly line. They have more intrinsic job satisfaction; are more satisfied with supervision, company, and union; they have more tension, feel more interference, more quality-quantity conflict; and are more job-involved than the men.

Most of these women were reasonably optimistic about their work. They liked what they were doing, and if bad material or other interferences prevented them from doing well, those conditions might conceivably be changed. They like the pay, pleasant associations with others, and generally sympathetic supervision . . . . Also contrasting with the assembly-line workers is the fact that the women could much more easily find jobs elsewhere; to give up seniority was not nearly so big a risk for them as for the men. The conflict involved in working was not as distinctive for them, since they could more easily escape it.[18]

Job Enlargement

A large manufacturer of home-laundry equipment has still a different type of assembly technology. Management's recognition of certain unfavorable effects of assemblyline technology has resulted in a deliberate program of removing jobs from progressive assemblylines and placing operators into newly designed single-operator stations. The term commonly applied to such a regrouping of work content is "job enlargement." In this case management undertook job enlargement and elimination of the assemblyline mainly in the hope of favorable productivity and quality gains; not only were these goals realized (the bench-enlarged job resulted in tangible savings of $2,000 yearly, chiefly because the job design sharply reduced nonproductive and balance-delay time), but many of the other work dimensions being considered were favorably affected as well.

The following brief review, from field research reported by Conant and Kilbridge of the Graduate School of Business, University of Chicago, is based on the experience of two the company's plants employing approximately 2,000 persons, with a United Automobile Workers local as bargaining representative for blue-collar workers.

> The case demonstrates, then, that there is an optimum extent for the division of labor on assembly lines. When the excessive division was reversed, hidden costs of nonproductive work and balance-delay (time taken by management to assign and reassign the minute job elements to each worker on an assembly line; a process which must be repeated every time there is a design or model change in the product) were squeezed out of operations and assembly time was shortened. The cost savings identified are based on tangible savings, principally labor costs. Improved quality, greater production flexibility, worker satisfaction, and other considerations are important to the economic arguments favoring job enlargement but are not needed to establish its desirability in this case.[19]

Thus, they suggest that the enlargement of many jobs in the American economy could be undertaken in the interest of cost reduction alone.[20]

The following summary of the effects on worker attitudes of this transfer from line technology to bench-assembly work is based on replies to a questionnaire given to 61 workers with at least 3 months' experience on both line and bench. They expressed approval of enlarged-job attributes in this order:

Freedom from being tied to the job (55).
Quality assignability (53).
Individual incentive opportunity (53).
Ability to contribute quality (52).
Opportunity to make complete assembly (50).
Ability to set own pace (48).
Greater amount and variety of work (47).
Learning time (38).

They most disliked characteristics of line assembly work in this order:

Inability to control quality on the line (51).
Absence of quality assignability (47).
The group incentive on the line (43).
The attachment to line jobs (42).
Line pacing (37).

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[18] Thomas M. Lodahl, "Patterns of Job Attitudes in Two Assembly Technologies," *Administrative Science Quarterly*, vol. 8, No. 4, March 1964, pp. 496–500.

[19] Eaton H. Conant and Maurice D. Kilbridge, "An Interdisciplinary Analysis of Job Enlargement: Technology, Costs and Behavioral Implications," *Industrial and Labor Relations Review*, vol. 18, No. 3, April 1965, p. 384.

[20] For a fuller discussion of the cost-reducing aspects of this case, see Maurice D. Kilbridge, "Reduced Costs Through Job Enlargement: A Case," *Journal of Business*, vol. 33, No. 4, October 1960.

To this summary, Conant and Kilbridge add the following comment:

> There is strong evidence that workers' inability to contribute workmanship (quality) and obtain credit for it was a most important source of dissatisfaction on the line. The general pattern of line response is impressively negative.[21]

Again there is behavioral confirmation that worker attitudes are reflected in their performance, i.e., the problems of quality that increasingly afflict the automobile industry. In a front-page story on July 21, 1965, the *Wall Street Journal* reported:

> Some authoritative critics are leveling broad charges that the number of poorly built cars is on the increase. *Consumer Reports* magazine recently charged: "The condition of 1965 cars the Consumers Union bought for test is about the worst, so far as sloppiness in production goes, in the whole 10-year stretch of deterioration that began in 1955 . . . minor, multiple, and annoying defects found in all 25 cars [purchased for test] added up to an overall impression of 'incredibly sloppy workmanship'" . . .
>
> One of the greatest quality problems is the danger of human error in the 4,000 to 7,000 assembly operations involved in building each car.

In an observation study of social interactions on the job, Conant and Kilbridge indicated that opportunities for social interaction were reduced by about one-half on enlarged bench jobs (distances to the operator's nearest and next neighbor were about twice what they had been on the line). Forty-five of the 61 workers queried preferred the social-relations aspect of line over enlarged bench jobs. Significantly, however, this negative factor was insufficient to influence the strong majority preference for enlarged jobs.

The Conant-Kilbridge findings examined against the eight work dimensions yield interesting results. Considering the first four—knowledge and skill requirement, pacing or rate of performance, degree of repetitiveness or variety, and portion of product worked on—the majority preferred greater skill, control over rate of performance, variety as against repetitiveness, and work on a larger portion of the product.

Findings on relationships at work, the fifth dimension, were more ambiguous. While a majority of the workers preferred the larger number of social interactions permitted by the assemblyline layout, this was overridden by the positive force of the other characteristics of the enlarged jobs. Designers of jobs should, however, weigh this dimension carefully. Personal interactions at work can be a most powerful source of satisfaction, and under certain circumstances subtracting them from the work situation will cancel out many of the positive elements of work satisfaction.[22]

Style of supervision, the sixth dimension, was not specifically studied by Conant and Kilbridge. As to the seventh, degree of workers' autonomy in determining work methods, autonomy was clearly increased, representing an important source of work satisfaction. The eighth dimension, relation of work to personal development both on the job and with respect to transfers and promotions, was not specifically studied, although replies suggest an awareness of this dimension's importance.

The relevance of the Conant-Kilbridge research lies not only in specific findings as related to the experience of one appliance manufacturer, but in their very wide applicability.

> There are several reasons for suggesting that these changes in job design may be relatively pervasive. The problem of balance-delay and associated labor costs is a prime problem in manufacturing assembly today. It has become more acute as consumers have demanded and technology has permitted production of more sophisticated and complicated goods. Henry Ford was pleased to maximize the advantages of his assembly-line technology by informing consumers that they could have any color Model A they desired as long as it was black. Today changing demand patterns, upgraded product performance requirements, new technologies and competitive market forces have required many manufacturers to increase variety, complexity, and quality of products. Firms are attempting, in effect, to produce custom-made products by mass-production techniques. *Partial failure in this is forcing more firms to reconsider assembly methods, and in some cases to revert to bench assembly, which fosters job enlargement.*
>
> . . . Workers may be affected in large numbers, and it may also happen that traditional sources of dissatisfaction with assembly work will be diminished.

Conant and Kilbridge conclude on this important note:

> We recognize, of course, that shifting assembly work from line to bench is only one form which job enlargement can take. The principle has many applications in both factory and office that are quite unrelated to progressive assembly.[23]

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[21] Conant and Kilbridge, *op. cit.*, p. 392

[22] Cf. "Job Enlargement in an Electronics Company," Thomas M. Lodahl and Charles R. Walker, unpublished study in Technology and Society Collection, Yale University. This study describes the negative effects of the absence of opportunities for interaction.

[23] Conant and Kilbridge, *op. cit.*, pp. 395 and 395r.

See in addition:

Robert H. Guest, "Job Enlargement—A Revolution in Job Design," *Personnel Administration*, vol. 20, No. 2, March–April 1957, pp. 13–14.

Chris Argyris, *Personality and Organization*, Harper & Brothers, New York, 1957, pp. 177–181.

J. Douglas Elliot, "Increasing Office Productivity Through Job Enlargement," *Office Management Series*, No. 12, American Management Association, New York, p. 13.

Earliest conscious application of the principle by management was in the IBM plant in Endicott, N.Y. See C. R. Walker, "The Problem of the Repetitive Job," *Harvard Business Review*, vol. 28, No. 3, May 1950, pp. 54–58.

Continuous Process Industries—Chemical and Oil Refining

Of all industries, the chemical and oil refining are the most highly automated, having introduced forms of automatic controls very early, long before the term automation was invented. It is not surprising, therefore, that the number of workers in these industries is, comparatively speaking, small and investment per worker is high. In oil refining, the most highly automatic of all, capital investment per production worker is $110,000, compared with an average of $15,000 for all manufacturing in the United States. Output per manhour increased 5.2 percent a year between 1947 and 1962, as compared with less than 3 percent for all manufacturing. For the chemical industry, the investment figure is $28,000 per production worker. Technologically, these industries belong in the more general category of process industries, of which basic steel is another example.

In applying the eight work dimensions to process technology, major sources of empirical data and findings are the studies of Robert Blauner, Davis and Werling, and the Technology Project of Yale University.[24]

It is interesting to quote Blauner on the first dimension: "The developing mechanization in continuous process technology results in an internal distribution of the blue-collar labor force that is different from the assembly line, mass-production industries. The most dramatic change is the reduction in the number of semiskilled operatives . . . since automatic processes do the work which these men would do in other technological situations . . . . There is also a striking inversion in the number of skilled craftsmen . . ."[25] (i.e., increase in skilled craftsmen compared with assembly-line technologies).

In one chemical plant which Blauner studied in detail, 40 percent of the work force were maintenance workers. In contrast to mass-production technologies, the blue-collar work force was highly stratified with respect to skill, status, job grade, department, and type of work; such stratification was clearly a response to the industry's technology.

As to the second and third dimensions, pacing or rate of performance and degree of repetitiveness or variety, instead of the mass production job cycles of a few seconds to a few minutes, Blauner writes: "The chemical operator's most standardized operation is his periodic round of readings which he takes every 2 hours. On such a round an operator may check the readings on more than 50 different instruments located at widely different points in his patrol area. There is a considerable variety, then, even in the most routine of the chemical operator's job tasks."[26]

This freedom of physical movement and a considerable choice in the timing of tasks largely eliminates imposed pacing and repetitiveness from the job. Whereas pressure and monotony were the commonest subjective expressions of dislike among the auto assembly workers, these factors appeared in almost none of the chemical workers' expressions of dissatisfaction. Eighty percent said they were free to set their own work pace.

The fourth dimension, relation to the total product or process, is one of the most important in all continuous process industries. The chemical worker, for example, is related to the total industrial operation—or to an important segment of it—in a fashion duplicated in few other work environments. Blauner writes: "The responsibility demanded of the chemical worker is a collective as well as an individual responsibility. Since the process is integrated and continuous rather than divided . . . the responsibility of any one employee for his share of a plant's process is inevitably linked to the responsibility of other workers. . . . [As a result] the very definition of responsibility as a job requirement involves a meaningful connection between the worker's own function and the goals of the entire enterprise."[27]

The fifth dimension, relationship with people as individuals or groups, is especially relevant for two reasons: (1) The operating work force of much of the chemical industry is organized into small groups or teams. ". . . Chemical-process operators are clearly identified with a particular shift and a particular department; the departmental work teams are not only clearly defined, they also have an explicit hierarchy of authority and status."[28] (2) The rate of interaction between workers on the job is relatively high although there are a few semisolitary jobs in chemical plants. The Davis and Werling study reports that blue-collar workers ranked "friends at work" as the most-liked element in the total job situation more consistently than 10 other factors, including interesting work, security, and pay.

With relation to dimension six, style of supervision and of managerial controls, whether administrative or technological, a few characteristics emerge from the nature of the process industries. Many worker-attitude surveys in many industries over the years have found strong preferences for "general" rather than "close" supervision, the typical comment being: "I don't want the boss breathing down my neck." Close supervision usually characterizes industries with a highly subdivided technology. In process industries the hand of supervision is lighter. Blauner writes: "The chemical workers interviewed all felt that the load of supervision was light and that they were given considerable scope to do their jobs in their own way . . . . The freedom is possible because the work team which runs an individual plant *takes over many of the functions of supervision in other technological contexts.* A worker will come to work and do his job well, not out of fear of a particular boss, but because he feels the other operators in his crew are depending on him to do his part of the total work."[29] [Emphasis supplied.]

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[24] Blauner, *op. cit.*, pp. 124–165.
Louis Davis and Richard Werling, "Job Design Factors," *Occupational Psychology*, vol. XXXIV, No. 2, 1960, pp. 109–32.
Charles R. Walker, *Toward the Automatic Factory*, Yale University Press, 1957.
Charles R. Walker, "The Basic Oxygen Furnace," unpublished manuscript, 1965.

[25] Blauner, *op. cit.*, pp. 131 and 134.

[26] *Ibid.*

[27] *Ibid.*, pp. 143 and 146.

[28] *Ibid.*

Dimension number seven, degree of worker's autonomy in determining work methods, has been encompassed in discussions of other dimensions. Autonomy in choosing work methods results, in part, from the absence of pressure which allows time for considerable experimentation in meeting new situations. Again, according to the Davis and Werling survey, 50 percent of the respondents stated that they usually plan how they do their job; 34 percent frequently do this; and only 6 percent said they seldom or never are able to plan their work.[30]

Finally, with regard to the eighth dimension, relation of work to personal development both on the job and with respect to transfers and promotions, the process industries contrast sharply with those technological environments which offer little difference in skill levels and a flat wage structure. Workers in the process industries typically function in teams that include a distribution of skills and defined responsibilities at all levels—job grades are likely to run from beginning helper to head shift operator. Thus, each job becomes a step on a natural ladder along which the worker may reasonably hope to progress, with an appropriate increase in training, responsibility, pay, and status.

Dimension four, relation to the total process, is clearly one of the most distinctive and satisfying features of process industries, but tangentially related to it is an element in the industry's work environment that is cordially disliked. This is the shift system, deriving from 24-hour operation. Other investigators have given considerable study to this element.[31] Blauner summarizes worker reaction as follows: "Changing shifts every 2 weeks prevented many workers from settling into satisfactory sleeping routines. *Night and weekend work stands out as the number one source of dissatisfaction of the chemical operators.*"[32] [Emphasis supplied.]

Then he gives the following condensed summary of the overall work environment of a chemical plant as seen by the workers themselves:

> . . . as compared to the textile mill and the automobile assembly line, continuous process technology leads to considerable freedom from pressure, control over the pace of work, responsibility of maintaining a high-quality product, choice of how to do the job, and freedom of physical movement.

In spite of such favorable features, however, Blauner asked the chemical worker if he feels and resents being controlled and dominated by the powerful technological complexes among which he works. A head operator in the company's ammonia plant answered in a generally typical fashion:

> If I want something to happen, I'll open a valve, and more product will be distributed to such and such a place. It's the operator who's definitely in charge and he runs the machine. The machine doesn't run him.

"The responses to this question," writes Blauner, "as well as other evidence, indicate that chemical workers do not feel dominated by their imposing technological surroundings but, instead, get feelings of satisfaction from the control of complex machinery."[33]

The average worker on automobile assembly lines welcomes breakdowns in technology as a means of relieving the pacing and repetitiveness of the line as well as his lack of freedom of movement. The autoworker also welcomes and often prolongs another type of "break" in his routine, through unauthorized or "wildcat" strikes. The chemical worker, on the other hand, appears strongly motivated, as Blauner writes, "to solve the problems caused by a breakdown in the technology and restore production to normal as soon as possible." This is in spite of the fact that "when there is a break in production he must work most frantically and under pressure . . . ."

Blauner concludes that these attitudes toward technology suggest chemical workers are more functionally integrated with the goals of management. It might be added that these workers are functionally integrated *because* the technology *permits* a wider span of interest and responsibility. It follows, then, that a fuller discussion of dimension four, relation to the total operation of the plant or unit which employs the worker, is indicated.

"The most critical feature of automation (in the chemical industry)," writes Blauner, "is that it transfers the focus of emphasis from an individual job to the process of production . . . . In this shift of emphasis from job to process, the worker's role changes from providing skills to accepting responsibility. His scope of operations increases. Continuous-process technology thus reverses the historic trend toward the greater division of labor and specialization." (This is essentially another type of job enlargement.)

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[29] Ibid. p. 147.

[30] Davis and Werling, *op. cit.*, quoted by Blauner, p. 139.

[31] Cf. for example, Floyd C. Mann and L. R. Hoffman, in their study of a powerplant, *Automation and the Worker*, Holt, Rinehart, and Winston, New York, 1960.

[32] Blauner, *op. cit.*, pp. 141, 142.

[33] *Ibid.*

In a typical chemical industry crew not all workers have the same degree of understanding or relationship to the total process as the leader. Nonetheless, even the least skilled worker with restricted duties and responsibilities is on the same promotional ladder and is a member of the same functional work group. The net result is that those in the lower ranks tend to identify with the whole crew and the total process. Confirmation of this is reported in a recent study comparing an electronic tube plant, a computer manufacturing factory, and a steel mill.

> The perception of workers in low-functional level jobs in steel manufacturing is almost identical to that of workers in high-functional level jobs in that industry and quite contrary to that of the workers in the other two industries. This is quite understandable since in the steel industry: (a) Both high- and low-functional level workers are members of a hierarchical team, operating in relation to a single huge machine; (b) the low-functional level crewmembers identify with the higher jobs which they expect to attain by seniority; (c) the low-functional level workers have a higher function (operating) than their counterparts in the other two industries who are feeding and tending; (d) when the low-functional level steel workers are talking about a less advanced technological situation, they are referring to one that is already highly automated; when the workers in the other two industries are talking about a less advanced technological situation, they are referring to handwork or to jobs in which they were in control of a nonautomatic machine rather than to an automated situation which utilized them functionally largely as feeders and tenders.[34]

Although the technology and job structure of the chemical industry and portions of the steel industry either demand or promote wider identification with the product and total process, even in less favorable technologies such identification can be greatly increased by progressive management policies. Examples can be found in accounts of union-management experience under the so-called Scanlon plans.[35]

The Davis and Werling survey of a highly automated chemical plant found 60 percent of the operators saying they knew all the stages required to complete the product. Surprisingly, this figure was higher than for maintenance repairmen and stockroom and shipping employees.

A feature peculiar to the technological work environment in the chemical and oil refining industries should also be mentioned: The worker's sensory relation to his product is totally eliminated, since the product goes its entire cycle in pipes or reactors out of sight of those manning the controls. Blauner speculated whether this might be a negative factor, and found it was not. In fact, the question had rarely occurred to the respondents. Of course, invisibility of the product does not hold for all process industries; in basic steelmaking, for example, the physical presence of molten steel is most of the time dramatically evident to all who work in the mill.

In summarizing, Blauner isolates and emphasizes four distinctive aspects of the work environment of a chemical plant which "enhance the worker's sense of providing a unique and important function whose purpose he understands." These are process production, team operations, the job requirement of responsibility, and the possibility of physical movement.

"Of these the technological factor of division of labor by process rather than by job seems to be the most important . . . ."[36]

Continuous Process Industries—Steel

The steel industry is roughly divided into two technological parts: First, those processes commonly called the basic steel industry through which ingredients are "melted" into raw steel products or ingots; and second, those processes by which ingots are transformed or finished into a vast variety of products, called, depending on the general nature of the product, tubing (pipe), flat-rolled products (sheets), etc. Both parts have undergone profound technological revolutions during the past decade.

Basic Steel

Significantly the revolution in basic steelmaking has occurred not through an application of automatic devices, although these are present, but through a new application of chemical principles to traditional ingredients. The units for turning molten iron ore and scrap into steel by this new method are basic oxygen furnaces, whose furnace load or "heat" receives at over supersonic speed a draft of oxygen. This enormously accelerates the rate of chemical reaction and multiplies the efficiency of the furnace by from 4 to 800 percent. The older, open-hearth furnace converts its ingredients into steel in 4 to 8 hours; a basic oxygen furnace produces the same quantity of steel in 45 minutes to an hour. In order to maneuver the heavy machinery that makes the oxygen furnace operable and to perform metallurgical calculations at necessary speeds, a variety of automatic devices, including a computer, are necessary. This whole complex of innovations is now rapidly transforming the work environment for basic steelmakers.[37]

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[34] "The Nature of Automated Jobs and Their Educational and Training Requirements," S. A. Fine, Human Science Research, Inc., McLean, Va., prepared for Office of Manpower and Training, Department of Labor Contract. OAM–3–63, June 1964.

[35] Douglas McGregor, "The Scanlon Plan Through a Psychologist's Eyes," in Frederick Lesieur (ed.), *The Scanlon Plan*, Technology Press, MIT, Cambridge, Mass., and John Wiley & Sons, Inc., New York, 1958, pp. 89–100.

[36] Blauner, *op. cit.*, p. 146.

[37] Today about 10 percent of the basic steel-producing capacity in the United States is in B.O.F.'s. Within 10 years, it is commonly predicted that the industry will consider the older open-hearth method obsolete.

Following is a discussion of basic steelmaking in oxygen furnaces with relation to work dimensions:

1. *Knowledge and skill requirement.* The higher skills in basic steelmaking have been, to some degree, absorbed by management and by automatic or semiautomatic technology. Notably, many of the skills in judgment and decision making of openhearth workers, especially those of the first helper, have been taken over either by the melter foreman or by automatic devices and data processing equipment. Some, although not all, of the other jobs of the several crews necessary to operate the furnace have lost a number of points in job class. The amount of heavy hot work has been reduced but by no means eliminated. Total manning force for a basic oxygen furnace is roughly the same as for an open hearth; therefore, technological displacement of workers will be due not to overall reduction in crew members, but to the need for fewer crews as units of production.

2. *Pacing and rate of performance.* As already noted, these are much faster. However, their character and impact are wholly different from that required by machines and assemblyline technologies. Essentially greater alertness and attention are demanded at certain intervals, rather than more rapid or dexterous physical movements.

3. *Degree of repetitiveness or variety.* Although the same operational steps are taken for every *heat* of steel, conditions vary sufficiently, heat by heat, to guarantee little monotony.

4 and 5 will be discussed below.

6. *Style of supervision and managerial controls.* For the blue-collar worker, the new steelmaking process, like the old, shares or divides necessary supervision between the melter foreman and the process itself. While this is not as striking as in the chemical industry, it is an important feature of the work process.

7. *Degree of worker's autonomy in determining work methods.* For all of the crew, the degree is substantially less than on the open hearth. But because metallurgical processes cannot, at least as yet, be wholly standardized in the manner of a machining operation, some latitude remains as to how and when each step is performed.

8. *Relation of work to personal development, both on the job and with respect to transfer and promotion.* Because of the relative newness of this type of work environment and the absence of studies in depth of its work dimensions, it is too soon to apply this dimension intelligently. However, the opportunity for the worker's personal development does depend on training programs and on management's ingenuity in integrating blue with white-collar careers.

To return to dimensions 4 and 5—*relation to the total product or process*, and *relationship with people as individuals or groups*—with respect to both, the effect on the individual is positive. Some of the psychological and social elements of satisfaction reviewed for the chemical plant also appear to be present in this new method of basic steelmaking. To illustrate, it is immediately and continuously evident to every member of the furnace crew, white or blue collar, that he is a participant in a *process* that is larger than the work contribution of any single individual and yet which continuously demands that contribution. Further, the "product" of each heat is physically or mentally vividly present and each member of the crew can *see* the completion of the product several times a shift. Finally, to achieve their common purpose, furnace crews must have freedom of physical movement and frequent verbal interactions.

Although working conditions are better than they are on the older open-hearth process, considerable hazard, heat, and heavy physical exertion, especially during emergencies, remain as negative features.

Steel Finishing

An early and substantial application of automation to the finishing portion of the industry was studied over a period of years by the Technology Project of Yale University and has yielded useful findings.[38] The study focused on a large automatic pipe mill, built and operated by the United States Steel Corp., in its tubing division. While results were simlar to those reported for basic steelmaking, certain dimensional differences were noted, the most important of which concerned pacing, rate of performance, and freedom of movement. The pipe mill was composed essentially of a mechanical complex of automatic devices, with each crewmember attached to a particular work station; therefore, there was little or no freedom of movement and pacing by the total machine complex was continuous. Nevertheless, the effect (after the break-in period) of this pacing is radically different from that in machining or assemblyline technologies.

Although men were stationed at different points, all were, and, in fact, felt themselves to be members of a close-knit team, manning a single massive unit of machinery. Split-second timing of their own motions, for the most part through the operation of levers, was integrated with every other man's physical and mental activity, and the product as it moved through a variety of finishing processes was continually visible.[39] Again, product visibility at all times contrasts with product invisibility in a chemical plant. On the other hand, the chemical worker does control through levers and buttons a much larger sequence of operations than the workers in automatic pipe mills.

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[38] Charles R. Walker, *Toward the Automatic Factory*, Yale University Press, New Haven, 1957.
"Life in the Automatic Factory," *Harvard Business Review*, January–February 1958.

[39] These characteristics of work are also noticeable in other modern finishing installations—blooming mills, sheet mills, tin mills, etc.

It is a characteristic of the steel industry, as it is of certain others concerned with metalworking, such as aluminum and copper, that the basic work unit is the group rather than the individual. Even where automation reduced the total manpower complement as in the pipe mill cited here, this primary structural feature was not changed, and cohesive crews continued to operate the mill.

As in basic steelmaking, the style of supervisory control was also distinctive. It was *shared* by the men as crews with their supervisors. The importance of these features were generally important to worker satisfaction.[40]

These relatively favorable appraisals are tempered by the realization that declining manpower requirements will continue to affect the attitudes and working lives of employees. Workers in large sections of the chemical industry experience little anxiety over technological displacement. However, in steel the opposite is true: Uncertainty as to future employment lessens present satisfaction with favorable dimensions in the work structure. As one worker in the automatic pipe mill put it:

> As far as I go, this new mill has been good for me because I can sit down or stand up, and I have all the "automatics." (His job consisted of the manipulation of levers.) It's certainly much better than it was when I had that heavy labor of rolling down billets. . . . But . . . look what happens to manpower. On the old mills we had about 21 or 22 operating people (per mill unit), and on this mill we only have 9. That cuts things in half . . . and most of the men . . . took a cut in job class. . . . So . . . you wonder whether all these improvements are good. . . .[41]

This comment was made when employment in the steel industry was still increasing; today the prognosis for manpower is a steady decline in requirements.

In 1953, the peak year for steel employment, the industry turned out 111.6 million ingot tons of steel with a production and maintenance force averaging 544,000 a month. In the first 6 months of 1965, with production running 2.6 percent higher monthly than in 1953 (partly the result of a strike threat), the production and maintenance force averaged 468,000. Some 100,000 blue-collar jobs have been lost in steel since the mid-1950's. The industry acknowledges that the number of workers needed to produce a ton of steel has declined by 2 percent a year since 1940, and if this continues and production by 1975 is, say, around 145 million tons, employment will be under 400,000. For its part, the union claims management's figures are too low. The union insists the decline has been nearer 3 percent and that the work force will be cut by nearly 40 percent by 1975 unless the demand for steel increases drastically. In addition, the ratio of white- to blue-collar jobs is constantly increasing, having risen from one in nine in 1934 to one in four in 1964.[42]

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[40] Walker, *Toward the Automatic Factory, op. cit.*, see especially, "After Three Years," p. 104, and "The Automatic Mill as a Work Community," p. 210.

[41] *Ibid.*, p. 183.

[42] Figures from *Business Week*, Aug. 14, 1965, pp. 75–78.

III. Solving Work-Related Problems

The most substantial example of cross-industrial research relevant to work dimensions as defined here is a 3-year project recently completed by Turner and Lawrence.[43]

The research is valuable and appropriate in three ways: (1) It is the first systematic investigation undertaken to test the weight and impact of the technological component in modern work across a wide spectrum of technologies; (2) it provides a practical methodology for *predicting* worker response to the characteristic attributes of work in the modern world; and (3) it recommends a number of ways for both diagnosing and meeting specific problems related to modern work environments. The Turner and Lawrence investigation introduces important innovations in method, content, and coverage. Sources include the British Medical Council (during and after World War I), the early work of Elton Mayo, the Tavistock Institute in Egland, the Centre des Arts et Metiers in France, and the Technology Project at Yale University. Of special significance is the frank objective to isolate and analyze each technological component in many industries, and to measure their impact on not only the attitudes but the behavior of individuals at work.

The study examined the work dimensions of roughly 500 workers in a sample of 47 jobs drawn from 11 companies. Industries were chosen for broad diversification as to technology and nature of work, as well as company size and regional setting. The sample also gave representation to other common classifications of American industry, such as job shop, mass production, process, and the "soft-" and "hard-goods" industries.

The term "task attributes" was used to describe and measure work characteristics. A requisite task attribute index (R.T.A.) was constructed and includes work characteristics corresponding generally to the dimensions used in this report and, in some respects, to the mass production index used by the Technology Project for studying the automobile industry.

To conceptualize job characteristics or task attributes as inclusively as possible, the investigators began with three major categories: Activity, interaction, and mental states. Activity included much of what has been described here as pacing, repetitiveness, or variety and autonomy in choosing work methods. Interaction included relations with people on and off the job, whether functionally required or discretionary. Mental states included knowledge and skill required and responsibility.

The full list of requisite task attributes is given below. The plus or minus factor of personal development is a deduction resulting from the application of the whole R.T.A. index. Promotions and transfers are omitted as a work characteristic because the intrinsic job itself is conceptualized as the object of study, rather than the job in a work sequence or on a promotion ladder as has been done here.

Hypotheses tested stemmed in a broad sense from the assumption underlying this report: That the technological component is strategic in molding the content of modern work. To frame this assumption in terms that are measurable and testable over a cross-industrial and cross-technological spectrum, each task attribute was quantified. For example, "knowledge required" was measured by learning time; "interactions required" were observed and counted. The entire list of attributes was run through for each job and then considered as independent variables. Workers' responses to the attributes were taken as dependent variables and were then quantified, in the main, by using two yardsticks: High or low attendance at work and expressions of satisfaction or dissatisfaction by workers themselves.

LIST OF REQUISITE TASK ATTRIBUTES

ACTIVITY:
- *Object Variety:*
  - Number of parts, tools, and controls to be manipulated.
- *Motor Variety*—average of:
  - Variety in prescribed work pace.
  - Variety in physical location of work.
  - Variety of prescribed physical operations of work.
- *Autonomy*—average of:
  - Amount of worker latitude in selection of work methods.
  - Amount of worker latitude in selection of work sequence.
  - Amount of worker latitude in selection of work pace.
  - Amount of worker latitude in accepting or rejecting the quality of incoming materials.
  - Amount of worker choice in securing outside services.

INTERACTIONS:
- *Required Interaction*—average of:
  - Number of people required to interact with, at least every 2 hours.
  - Time spent in required interactions.
- *Optional Interaction on-the-Job*—average of:
  - Number of people available for interaction in working area.
  - Time available for interaction while working.
- *Optional Interaction off-the-Job:*
  - Amount of time worker is free to choose to leave the work area without reprimand.

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[43] Arthur N. Turner and Paul R. Lawrence, "Industrial Jobs and the Worker," Harvard University, Graduate School of Business Administration, Boston, 1965.

MENTAL STATES:
 Knowledge and Skill:
  Time required to learn to perform job proficiently.
 Responsibility—average of:
  Ambiguity of remedial action (to correct routine job problems).
  Time span of discretion (maximum time before marginal substandard work is detected).
  Probability of serious (harmful or costly) error.

Hypotheses tested were:

1. That satisfaction would be high on jobs with a high R.T.A. index, e.g., jobs high on autonomy, responsibility, and interaction opportunities, and that satisfaction would be low on jobs with a low R.T.A. index, e.g., where autonomy, responsibility, and interaction opportunities were low.
2. That workers on jobs with high R.T.A. scores (more autonomy, responsibility, etc.) would stay on the job more consistently and so have a higher attendance score; and conversely, those on jobs with low R.T.A. scores would have low attendance records.

Generally speaking, these two major hypotheses were validated. Other factors influencing work life—for example, supervision, the union, wages, and personality traits—were also fully considered, and detailed tables were presented on their general effects as supplementary variables. The most important and definitive finding, however, was that no matter how supplementary variables influenced individual worker response, for the total population studied the technologically determined job attributes dominated worker response. This was true whether that response was positive or negative.

Among many practical recommendations for solving work-related problems, the following are particularly appropriate for this report: Where the existing technology imposes simple job characteristics with little variety, responsibility, or skill, Turner and Lawrence suggest that management increase variety through job rotation. Even within highly automated technologies, autonomy and responsibility may be increased "through encouraging worker decisionmaking on many aspects of quality control, scheduling, etc., as well as on issues directly related to task attributes, such as hours of work and rest pauses. . . ." They also recommend that management experiment with a "selective form of job enlargement. Often a careful investigation of a particular situation may show that the particular attributes which are contributing most to workers' dissatisfaction can be considerably 'enlarged' without any significant change in the basic technology."

Turner and Lawrence also say about technological change: ". . . Undesirable consequences . . . can be avoided to the extent that workers actively participate in recognizing the need for change and in planning its impact. [They are then likely] to have both the predisposition and the ability to devise ways of adapting to needed change while preserving existing levels of commitment to the importance of the work itself and of total organizational goals."

This body of cross-technological research would seem to have taken a useful step in bridging the gap between broad statistical surveys of modern work and such case material as was analyzed in section II of this report. It should be broadened and applied to several strategic segments of modern work, notably those areas where conversion to automatic or semiautomatic operations is creating drastic dimensional changes for both blue- and white-collar workers.

An examination of the case studies of different technologies in section II and the Turner and Lawrence cross-technological research, suggests this operational finding: That each individual occupation (as conceived and described here) consists of two halves, the hardware half or machine complex and the organizational structure in which it is imbedded. The machines and tools the worker uses or the control board he operates are examples of the hardware or machine half of his work environment. The administrative or organizational system as it impinges on him, together with all skills and techniques imparted to him and which he controls or which control him, make up the other half.

It follows—and this has been found in practice—that a man's work in modern industry *can be redesigned* in two ways: By changing the hardware portion of his job, or by changing the organizational structure that surrounds it. It is also possible and useful in some cases to change both.

For example, the home-laundry manufacturer initiated a machine change by abolishing assembly lines and setting up separate work stations because of quality defects in the product and a "balance-delay" problem with the assembly technology. To do this, the company's engineers had to design new machines to enable each worker at every machine to put together the total product. In this case by redesigning the hardware, management gained a double advantage: Cost reduction and a more satisfying and rewarding job for the operators

One of the most successful examples of a deliberate redesigning of the whole organizational part of the work complex may be found in the British coal mining industry. With the introduction of a new type of mining machinery the old work groups among miners were broken up. Dissatisfaction and an increase in accidents and illness accompanied this change. A careful analysis of both the organizational structure and the technology showed that it was possible to operate the new coal-cutting machines with a revised group structure. The new hardware was left unchanged but the organizational structure into which it wa fitted was revised. Greater efficiency plus a satisfied work force resulted.[44]

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[44] For an account of this, see E. L. Trist, "Work Organizatio at the Coal Face," Mental Health Research Fund Conference o Research on Stress in Relation to Mental Health and Menta Illness, Lincoln College, Oxford, July 15–19, 1958.

IV. Strategic Role of the Engineer

The old question is still being asked: Does automation (and other technological innovations) result in an increase or a decrease in skills and responsibilities of workers? Or, in more general terms, is work experience becoming more or less rewarding for the average man? Whether or not such questions can ever be answered generally, they are indeed being answered in specific terms every day, industry by industry. More especially, they are being met and answered in terms of blueprints, mockups, and models of new products from research and development departments, and by those whose business it is to translate these promptly into new occupational structures. This is the typical sequence in the genesis of a technological innovation of a product: (1) Research is done by scientists and engineers into a new and promising technological idea or into a new configuration of old ideas. This may take from 5 to 10 years; (2) blueprints are made, followed by laboratory experiments, models, and mockups by product engineers; (3) jigs and fixtures are designed; (4) layout, work assignments, time-and-motion studies, etc., are made by industrial engineers in cooperation with production management and personnel; and (5) trial production runs begin.

In section I, the engineer was suggested as the strategic architect or designer of the dimensions of modern work. Like other architects, he must plan subject to certain fixed limitations; and as with the designer of a new building, time, costs, and materials represent three of those imposed limitations. But also like the designer of a building, the designer of new technologies and the work structures into which they will be fitted has a certain latitude. He can make the work structure thoroughly unsatisfactory or even dangerous for the man who must live in it every day, or he can model it with more satisfactory dimensions. In short, the author is suggesting that the nature of human work as it develops over the next decade is, in a considerable degree, within the control of the engineers and managers who will design the occupational structure.

However, many elements in the new hardware or organizational structure are frequently frozen too early, leading to the inclusion at the manning stage of many technical innovations with features undesirable both from the standpoint of operating management and the worker. These might have been eliminated had consideration been given to them at the stage of blueprinting, etc. (see (2) above) or of designing jigs and fixtures. In a recent installation of partially automatic equipment in a steel mill, personnel men, industrial engineers, and representatives of operating management, including foremen, were active participants in the development of the innovation from stage (3) on. And in the U.S. Navy, it is now standard practice to study quantitatively and qualitatively manning problems of new mechanisms at an early stage before models are frozen.

Another example of work-design opportunities is the case of numerical control, a technology, as noted in section I, which is the latest stage in transfer of skills in the machine tool industry. Numerical control is a product of R&D created to order to meet the need of the Air Force and the aircraft manufacturer for machining techniques that would produce intricately designed parts for high-speed planes. These parts had to be made cheaper, faster, and more accurately than was possible under conventional methods. Originally regarded as a tool, numerical control is now becoming a system, viz, the well-advanced and widely used A.P.T. (automatically programed tool system).

Two other characteristics of numerical control are important. First, as a cross-industrial technology, it is applicable to many if not all of the 29 metalworking industries. Also being discussed and tested is its extension to other types of operations, such as drafting, riveting, welding, inspecting, and molding, among others. Thus, this automatic technique has implications for many industries with different technologies. Second, applications are sufficiently new and experimental that occupational structures into which numerical control is being fitted are not yet frozen. A Department of Labor study comments: "Because numerical control is a new field where procedures in most of the operations still are being developed, occupations, job titles and duties do not yet follow a well-defined pattern."[45]

This statement is well documented and has been given organizational and behavioral significance by several investigators through interviews and questionnaires.[46] Major conclusions which may be drawn from all investigations to date are:

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[45] *Outlook for Numerical Control of Machine Tools, A Study of a Key Technological Development in Metalworking Industries,* Bureau of Labor Statistics, Bulletin No. 1437, March 1965, pp. 33–45.

[46] For this discussion of the impact of numerical control on dimensions of human work, the writer is particularly indebted to Lawrence K. Williams and C. Brian Williams, "The Impact of Numerically Controlled Equipment on Factory Organization," *California Management Review,* winter 1964, and for a broader discussion of new technologies and work, to Peter B. Doeringer, "The Theory of Internal Labor Markets," unpublished Ph.D. thesis, Harvard University, 1965, and Michael J. Piore, "Impact of Technological Change on the Skill Content of Jobs," unfinished Ph.D. thesis, Harvard University, scheduled for completion, spring 1966.

(1) Depth and force of the impact of numerical control on the whole organizational structure is profound; and (2) uncertainty still prevails as to its influence on the work dimensions of many individuals. Followup investigations in particular industries are, therefore, called for. L. K. and C. B. Williams, who studied the impact of numerical control through interviews and extensive questionnaires with 33 users and 6 producers, emphasize several major organizational impacts. Each implies certain behavioral and psychological problems attendant on dimensional changes in the work of individuals and groups.

Major users of "automation in the office" have long observed that one of the great benefits of the computer has been the rethinking and the reshaping of organizations which it compels. Hidden costs have often been revealed and improved methods adopted even before savings were realized from the computer itself. Now evidence accumulates that the same preinstallation benefits are being realized from numerical control in the factory.

Williams and Williams in their broad survey document certain predictable impacts. Among these are a number of occupational candidates for displacement, for example, the skilled craft of a tool and die maker. (To date, few of these craftsmen have actually lost their jobs, but no new ones are being trained in many companies.) Another is the technically trained first-line supervisor. For perhaps obvious reasons, many decisions formerly made by the supervisor—allocations of work, to name one—are now made at a higher level and far from the factory floor. Two other predictable results of numerical control are, of course, the creation of a new occupation, that of programing, and the addition of electronic engineering skills to the maintenance department.

However, from the standpoint of this report the most fundamental and far-reaching change is the new location and character of the decisionmaking process. That decisions would be lifted to a higher point in the organizational hierarchy was predictable, but many of the behavioral effects of this change were not. The nature of numerical control technology dictates several features that characterize the decisionmaking process and determine its location. Minor decisions on work allocation and quality of product, formerly made over a period of time and on the factory floor, must now be made once and for all. The high cost of equipment implies heavy penalty for idle machines, and there must be no down time. By the same token the cost of planning errors is far greater than it is on conventional equipment. Williams and Williams report, "The error often is not the fault of the operator of the equipment, because his opportunity to deviate from the planned sequence of machine operations is normally restricted. Usually the performance failure can be traced back to design; to a translation of the design into programing information; to a conversion of the programing information into numeric information; or to the preparation of the punched tape."

These wholly new dimensions in the decisionmaking process account for many of the unanticipated consequences for organizational behavior Certainly departmental units are less independent in a numerically controlled factory than a conventional one. Interaction must, therefore, be clos and frequent. As Williams and Williams remark "Essentially units become interdependent and hav fewer areas of freedom. Maintaining productivit becomes a continuing cohesive force." Anothe result of numerical control is its introduction o a new problem in communication—or put mor positively, it demands new channels of communication. Traditional channels, which go up to th top in one division and over and down into another are too slow and cumbersome; also the particula level within, say, a manufacturing or engineerin division at which the failure occurred may be bypassed under the old arrangement. Some companies now use multidepartmental committee made up of representatives from the various level of their operating units. Another communication problem when computers are used is posed by th introduction of a novel language, the syntax an vocabulary of the computer, which must be learne by many of the personnel. (An advantage of th multidepartmental committee is that it permits an promotes the use of this common medium o communication.)

Another important result of numerical contro installations is unexpected: The importance of th skilled machine operator is increased rather tha decreased, a result of the new decisionmakin functions and the "once-and-for-all" taping o production runs. Since it is *his* skills and *hi* knowledge of actual machine performance tha have now been transferred to the tape, his pas experience best equips him to anticipate actual outcomes on the factory floor; and by the same toke to correct planning errors made at the source.

Williams and Williams conclude: "The operato is in a position to be of great assistance, or hinde ance, to the other members of the numeric contr system. He is also in a position to evaluate th performance of the input of these other grou contributing to the numeric control effort. A goo operator can feed back performance data and ca often correct for errors introduced by others. low-level operator, who may have little knowled of what is happening, is not able to feed back i formation. Above all, he is not in a good positio to correct errors. He can only shut the machi down (or worse, cause damage to it) and call f help, thus revealing the performance failure to the whole organization."

It must be emphasized that the whole phenomenon of the numerically controlled department or factory is still in its early stages, and many occupational classifications, including that of machine operator, are still undefined. Nevertheless, the incumbents of certain jobs are in strategic positions and may well retain them for some time.

Williams and Williams suggest that organized labor's policy, as a rule, is to accept the fact of a reduction in the daily exercise of certain former skills but also "to argue that the cost of the equipment and the cost of an error is so great that the classification of the individual should be maintained or even raised. The shift is from claims based on job skill to job responsibility."

The latitude enjoyed and exercised by industrial engineers, managers, and personnel departments is still appreciable, not only with numerical control but with many other installations of automatic machinery as well. Practices observed by Doeringer and Piore show that knowledge and skill required (dimension one) and personal development on the job and promotions (dimension eight) are frequently within the control of management through decisions made by industrial engineers or managers. For example, an automatic installation may result in a new occupation, designed as the simple monitoring of a machine, but the job specification may be written to include a quota of maintenance; or it may, in addition, encompass inspection. Considerable latitude is also introduced in the ladder of promotion as a result of changing technologies—some managements have succeeded in maintaining or creating promotion ladders for blue-collar workers, while others have been disposed to remove highly skilled jobs from the blue-collar category and assign them to exempt employees.

The tendency of certain technological innovations to create ceilings or dead ends for blue-collar workers creates a problem for many hourly employees from the standpoint of a healthy work career. This was emphasized by the Yale technology project's comparative studies of the impact over a 10-year period of conventional and of automatic technologies on the working lives of men in the steel tubing industry. The question of promotion was summarized thus:

> There are two interrelated factors that are likely to influence strongly the harmony of any automatic mill . . . education and promotion. The workers believed that there was an all but impassable educational barrier to their own advancement in automatic mills. . . . More and more, they said, the mill man with his practical skill and experience will be unable to rise as in the past unless he has had a technical education. The future belongs to the college boys, the slipstick men (technicians using a slide rule) and the engineers.

The study concluded that:

> The nationwide trend toward automation as such will create a large and many-sided educational problem in the next decade. The demand for education both inside and outside the industry will grow. Of this fact there is already much talk and wide recognition. *What is less well understood is the two-sided problem stressed by the men* . . . . They were saying: "Mills like Number 4 and all other automatic mills of the future, will need more technical men, that's understood; but isn't there a way of bringing in the engineers without losing the hard-won qualities of 'millwise' men, with their skill in human relations and in man-boss relations which the 'college boys' haven't got?" [47]

A part of the response to this problem can be found in more night courses by more colleges in more cities for blue- and white-collar workers, and some increase in the quality and scope of on-the-job training in industry. But so far the effort and results are small compared with the need. Fortunately more courses in the social and behavioral sciences are being given in the country's leading engineering schools with the result that new designers of jobs hopefully will be better equipped to weigh both the technical and human factors in the new occupational structures they will be called upon to design.

On May 14, 1965, the national convention of the American Institute of Industrial Engineers held a symposium on utilization of the behavioral sciences in the practice of industrial engineering, suggesting a growing interest by engineers in the dimensional approach to human work. The symposium was attended by practicing engineers representing a variety of industrial technologies: electronic instruments, clothing manufacturing, filmmaking, home applicances, and heavy machinery; also participating were educators, some of them industrial engineering teachers and other behavioral scientists. In the course of the sessions, a number of company experiences were reviewed in the light of both engineering and behavioral principles. The following typical experience of one company illustrates the practical usefulness for the engineer of looking at modern man-work-machine complexes through both behavioral and technological windows.

The company's medical department was concerned with a growing volume of physical complaints from the work force. They turned to the industrial engineers who in collaboration with the medical staff began to investigate workload and working conditions.

Surveying a variety of jobs where incentives could be isolated in relation to worker output, the engineers found several job groups where both output and morale were higher than in other groups with higher pay differentials. In these high-morale areas, the relation to the total product or process, that is, dimension five, was favorable: Each worker could see the product as he worked on it and when it was completed.

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[47] Walker, *Toward the Automatic Factory*, *op. cit.*, pp. 214–215.

The industrial engineers then broadened their application of traditional standard engineering practices to study the whole man-machine complex. Inquiring into neglected dimensions, they focused particularly on introducing changes based on a new concept of the blue-collar worker's role in the total manufacturing process.

As as result, they inaugurated two rates of pay for workers: One was related to the worker's productivity; the other was for those willing to acquire additional skills. Especially notable was an arrangement by which a premium was paid to workers willing and able to do several jobs and also to be flexible as to tasks they performed from day to day. It was this flexibility, appropriate to our changing industrial world, that proved both satisfying for the worker and useful to management.

Redesigning elements of other jobs resulted in operators finding them more meaningful, both with relation to themselves and to the jobs of others. Finally, the engineers made innovations in an area called goal and information flow, by which they informed workers on the current overall policy of the company and how each individual's work fitted into the total manufacturing process.

V. Findings and Recommendations

1. Because of the enormous growth of scientific and engineering research over the past decade, the technological component in human work has become decisive in defining job dimensions in the modern world.

2. The rapidity, depth, and extent of changes offers managers and engineers a twofold opportunity: To redesign human work in the interest of maximizing the quality and the quantity of the product and to redesign it in the interest of the basic human needs of men and women at work. Limits exist in both areas, but the degree of flexibility is greater than currently realized. In many cases the two are not in serious conflict, and where they are, a compromise should be fully explored, considering the interest of both parties.

3. Old work environments should be analyzed as well as the new from a broad dimensional approach, using the kind of analysis illustrated in this report or another of equal scope.

4. Success in changing either the hardware or the surrounding organizational structure within new work environments depends upon a major factor—*timing*. In the genesis of new products and new technologies, the point of maximum flexibility should be seized by managers, engineers, and behavioral scientists. An outstanding example of advance planning and interdisciplinary cooperation between the physical and the life sciences may be found in certain areas of the aerospace industry.

5. With intelligent planning, an enormous reservoir of skills, both technical and psychological, can be conserved and made productive in the transition from old to new technological work environments. Two examples, cited in this report, are automatic and semiautomatic steel mills, and most of the industries installing numerical control systems.

6. If managers and engineers, as architects of the future, are to meet the fundamental needs of their clients, they must study the individual and group personalities of those who will occupy the industrial world they have been called upon to design. Universities and engineering schools probably hold the key to that broadened understanding.

7. It is as important to appraise the differences as it is the similarities between one work environment and another. Some new technologies bring features favorable to workers; others introduce new types of stultification, danger, or instability. There is no substitute for an objective examination of each work environment by responsible managements and unions that makes full use of the analytic tools of behavioral science.

8. The quality of civilization cannot be divorced from the work men do and the tools they use within the society which gives that civilization its form and content. Not machines themselves but the ways they are *designed*, *used*, *or abused* determine the quality of industrial society.

Part 4

HOURS OF WORK AND LEISURE

HOURS OF WORK ISSUES

Prepared for the Commission
by
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PREFACE

This paper is part of a more extensive analysis of the "Hours of Work" issues sponsored in part by the Berkeley Unemployment Project. I acknowledge the assistance of John Bertucci, Alan Hess, and Richard Bell in the preparation of this paper. I am particularly grateful to Professor Clyde Dankert, and to the contributors to *Hours of Work* (Harper and Row, 1965) for their courtesy in providing prepublication copies of their material, and to the many individuals in the Department of Labor who provided data and friendly advice.

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Hours of Work Issues

Introduction

There are two quite different issues involved in an examination of the "hours of work" question. One is simply whether the long-run reduction in the workweek will continue into the future. The answer is related to the relative value placed on leisure and income by American workers; to the changing industrial, occupational, and labor force structures; and to the implications of workweek reduction for productivity, costs, and growth. The second issue is whether it would be desirable to use the power of government to reduce the workweek, either through an increase in the overtime penalty rate and/or through a reduction in the standard workweek. Although this question could be related to the social desirability of increased leisure, workweek reduction has been considered primarily as a means of increasing employment by spreading available work. These proposals must be evaluated in terms of their employment-creating potential and their costs relative to other policy alternatives.

This paper represents an attempt to shed some light on these issues through a preliminary analysis of workweek and overtime patterns and an examination of the major implications of workweek restrictions.

The Path to 40 Hours

In the 1820's and 1830's[1] pressure to reduce hours came from sporadic work stoppages and political agitation. Since unions were generally very weak and frequently did not survive strikes or depression, it might not be accurate to credit collective bargaining with the general hours reduction. However, the introduction of the 10-hour day for many skilled craftsmen in building trades and printing appears to have been, at least in part, a response to direct action. Political action had little direct effect on working hours. A few State laws had been passed regulating the hours for women and children, but even these were unenforced. President Van Buren's executive order in 1840 which ordered conformity to the 10-hour system on the Government's public works had little impact on private employers.

After the Civil War there was renewed agitation for reduced hours of work. A network of "8-hour leagues" and the National Labor Union, which was organized in 1866, lobbied actively for legislation at the State and Federal levels. But the State laws that were passed were ineffective, and even the law establishing an 8-hour day for Federal employees was interpreted by the courts as only a "direction by the Government to its agents." After the depression of 1873 to 1879, the labor union movement attempted through unified action to achieve the 8-hour day. Temporary successes were made by some organizations of skilled workers, but after the reaction to the Haymarket Affair, many of the gains were lost and the momentum of the organized effort to reduce hours was lost. In 1890 the carpenters succeeded in winning an 8-hour day in many cities, but instead of being the forerunner of a general shift to a shorter workday, their advance stood for a long time as a fairly isolated instance of the successful application of bargaining power.

The historical data show a relatively steady but gradual decline in hours of work from 1850 through 1900. There is no evidence of any dramatic impact of either the 10-hour or 8-hour movements, and it appears likely that the underlying economic forces, including the increasing reluctance of workers to work excessive hours, were at least as influential as political activity or direct union action (see chart 1).

From 1900 to 1920, weekly hours of work in the nonagricultural sector of the economy dropped at a rate about 2½ times as fast as over the preceding 50 years, although manufacturing hours apparently did not participate in the accelerated hours reduction until about 1909. In the unionized sector of the economy several of the stronger

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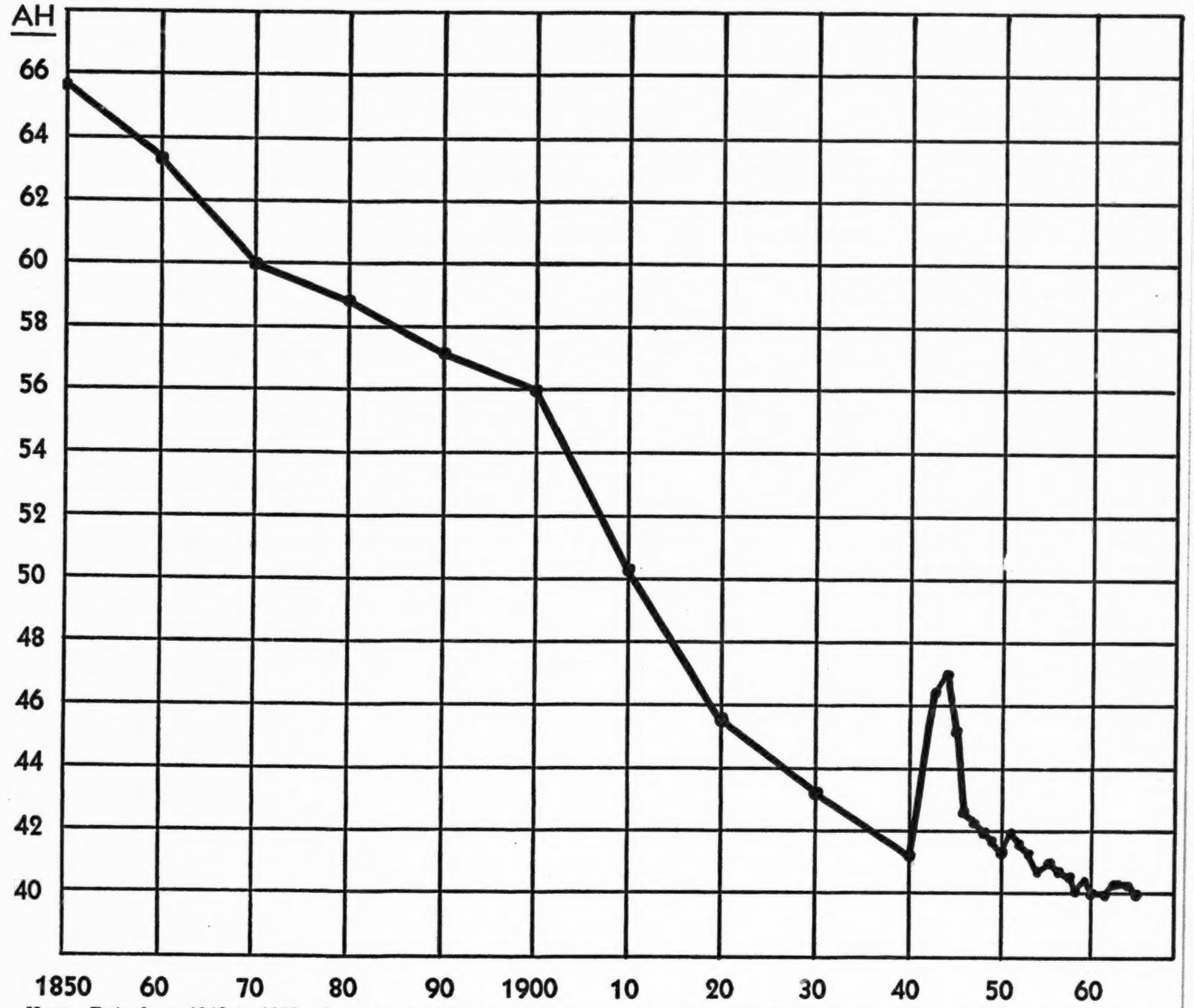
[1] The historical summary is based on a number of sources, including: Marion Cahill, *Shorter Hours,* Columbia University Press, New York, 1932; Commons and Associates, *History of Labor in the United States,* Macmillan Co., New York 1918, 1935; Ray Marshall, "The Influence of Legislation on Hours" in *Hours of Work,* edited by Clyde Dankert, Floyd Mann, and Herbert R. Northrup, Harper and Row, New York, 1965; Richard L. Rowan, "The Influence of Collective Bargaining on Hours", in *Hours of Work, op. cit.;* Milton Derber. "The History of Basic Work Hours and Related Benefits in the United States," in *Studies Related to Collective Bargaining Agreements and Practices Outside the Railroad Industry,* Appendix Vol. IV to the Report of the Presidential Railroad Commission, Washington, D.C., February 1962; George Brooks, "The History of Organized Labor's Drive for Shorter Hours of Work," AFL–CIO Conference on Shorter Hours of Work, September 1956; Gordon F. Bloom and Herbert R. Northrup, *Economics of Labor Relations,* Richard D. Irwin, Inc., Homewood, Ill., 1961; *A Shorter Work Week?,* Chamber of Commerce of the United States, Washington, D.C., 1962; Sar A. Levitan, *Reducing Worktime as a Means to Combat Unemployment,* W. E. Upjohn Institute, 1964.

CHART 1. *Nonagricultural Hours of Work, 1850–1964*



NOTE: Data from 1943 to 1963 relate to actual hours of work during the survey week by members of the labor force who were at work. Data are for the month of May of each year and reflect hours worked at all jobs during the week. These figures are based on interviews obtained in the monthly survey of households.

SOURCE: 1850–1940; Dewhurst & Associates, *America's Needs and Resources,* 1955. 1943–63; U.S. Bureau of the Census and U.S. Bureau of Labor Statistics.

unions succeeded in reducing their working hours, and more effective legislation was passed that set an 8-hour day for certain Federal employees, as well as for employees of contractors on Federal projects. In 1916, Congress passed the Adamson Act which established an 8-hour day on the Nation's railroads, and during World War I the War Labor Board and its umpires helped to spread the 8-hour day.

In the first two decades of the twentieth century, working hours were reduced through a combination of collective bargaining, Federal legislation, administrative acts, social pressure, and a changing environment in which the 8-hour day became the standard schedule in a growing sector of the economy. The reduction of hours was by no means uniform and was more easily accepted by industries with flexible production techniques, while others, such as the steel industry, vigorously resisted the trend for some time.

The trend toward a shorter workweek was apparently checked in the 1920's, a period of strong employer opposition to unions and limited union strength. The evidence, however, is somewhat mixed. The average hours series of the Bureau of Labor Statistics for manufacturing production workers shows a decline of 2.1 hours from 1919 to 1929. The sharpest reduction was in 1921, after which the workweek fluctuated above the 1921 low. However, a series of hours actually worked per week by manufacturing production workers constructed by Ethel B. Jones[2] shows that in the period from 1919 to 1929 the workweek increased almost 2 hours. Data from other sources show that average hours in nonagricultural industries did not fall as rapidly after 1920 as they had in the previous two decades. The weight of the evidence seems to support the view that in the 1920's the pace of workweek reduction slowed down.

The year 1930 brought a sharp increase in the unemployment rate as the economy moved toward a depression. At the same time, hours of work fell sharply. The Jones series shows a fall of 4.4 hours from 1929 to 1930, while the BLS series estimates a reduction in the workweek of only 2.1 hours. In any case, it was a substantial decline for 1 year, and the workweek continued to fall rapidly until 1934, as employment opportunities disappeared and as many employers scheduled short workweeks to spread out the available work among their employees. The National Recovery Administration facilitated hours reduction, and many industries adopted 40-hour standards with some going well below that figure. Many of these short workweeks continued to be standard after the NRA was killed by the Supreme Court. In 1936 the workweek increased to about 39 hours as the economy improved, but plummeted sharply again to 35.6 hours (BLS series) as the economy faltered again in 1938. In this depression, Congress passed the Walsh-Healey Act, which established a 40-hour standard for Government contract work (1936), and the Fair Labor Standards Act of 1938, which defined a standard workweek for covered establishments and required a time-and-one-half penalty rate for overtime hours. The standard (straight-time) workweek was reduced in stages from 44 hours in 1938 to 40 hours in 1940. As I will suggest later, it is very difficult to assess the impact of this legislation on the workweek.

As the economy moved into war production from the trough of 1938, the workweek rose even more rapidly than it had fallen in the Depression. When the war ended, the manufacturing workweek fell from the 45.2 hours war peak to 40.3 hours in 1946. Since then the workweek has been relatively stable. Chart 2 shows how different series describe changes in the postwar workweek in comparison with earlier periods.

The End of a Trend?

At first glance it appears that the workweek has stabilized in recent years and that the long-run trend of hours reduction has finally stopped. However, the data are not easy to interpret. Whether or not the trend has changed depends on how the trend is defined. For example, from 1870 to 1900, the workweek fell only 4.1 hours. And we have probably done about as well as that since 1946, particularly if increased vacations and holidays are taken into consideration in computing average hours of work. Using the Jones series for manufacturing production workers, a trend line drawn through the data from 1900 to 1929 and then extrapolated into the 1960's would project the workweek for 1964 very close to the actual figure. In other words, the 1964 workweek seems to be consistent with some definitions of the long-run trend.

However, hours reduction has not proceeded at a steady pace over time. The workweek has declined rapidly in some recession periods, such as 1921 and during the Great Depression of the 1930's. The sharpest nonrecession reduction in hours took place during World War I from 1916 through 1919, when evidently a relatively tight labor market and the rulings of Government boards helped to spread the shorter workweek throughout American industry. Working hours have been relatively stable since the end of World War II, but there have been similar periods of stability in the past which were followed by accelerated workweek reductions. The long-run trend in the twentieth century shows an average decline in the workweek of about 2½ hours per decade. The postwar record has not matched that pace, but it is too soon to conclude that relatively short-run variations will not average out to the trend figure in the future. The spread of longer vacations and strong pressures from craft unions and other bargaining power centers for shorter hours suggest the path of change.

The Lessons of History

It is difficult to identify the lessons to be learned from the historical record. Although the mass movements and political activities associated with the shorter-hours movement before 1900 did not produce dramatic short-run effects, they may have created an environment and expectations that facilitated the sharp reduction in hours during World War I. Collective bargaining cannot be given major credit for the reduction in the workweek prior to 1930, since unions represented only a small minority of the labor force. However, some unions, notably in the building trades, were able to use their bargaining power to reduce working hours substantially, and in doing so undoubtedly helped to set the pattern for the rest of the economy. Although the early legislation was ineffective, the sharpest reduction in the workweek was accomplished with the help of the Government during World War I, and the rapid reduction of the workweek after World War II might be attributed to the Fair Labor Standards Act and

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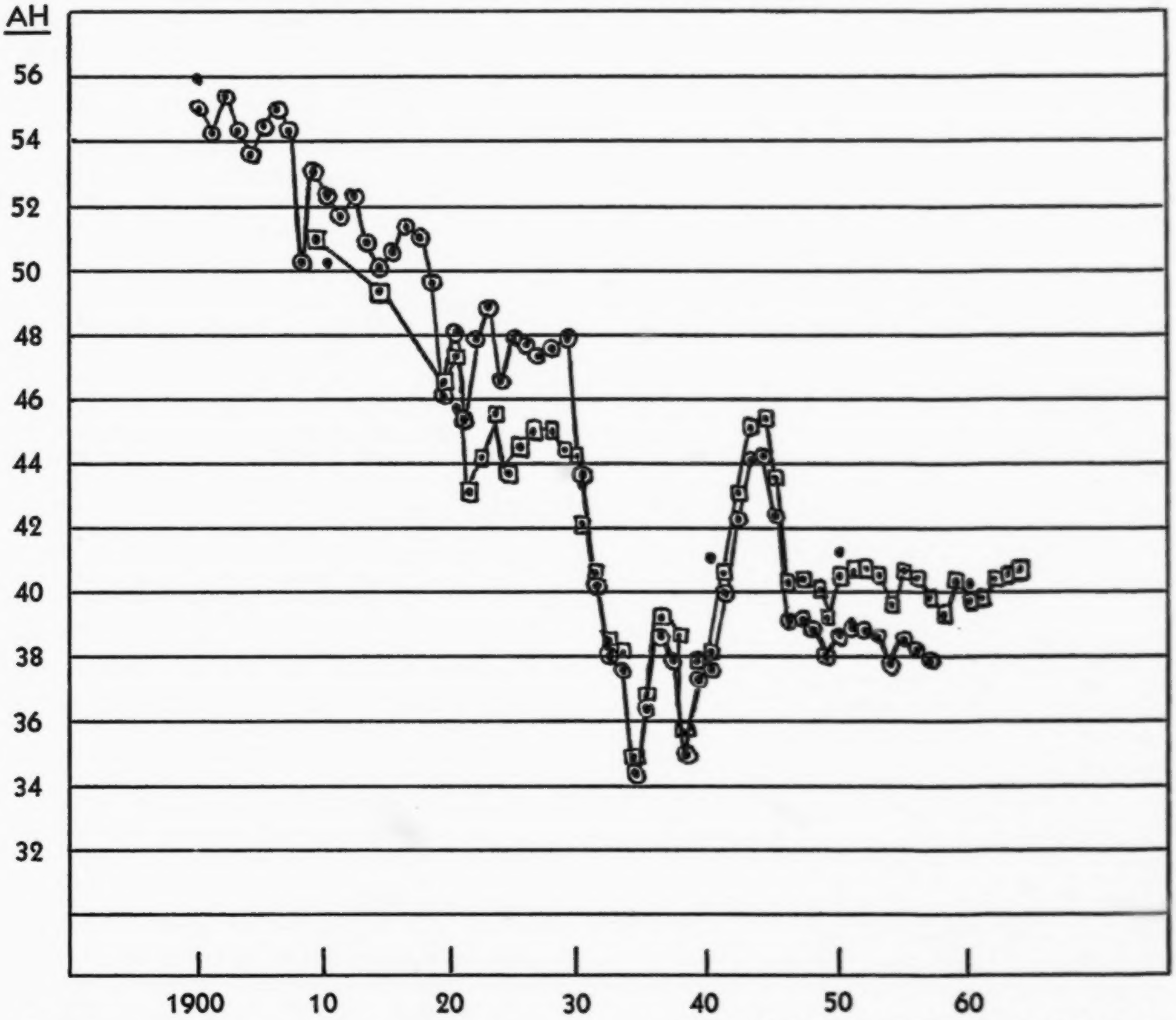
[2] Ethel B. Jones, "New Estimates of Hours of Work per Week and Hourly Earnings, 1900–1957," *Review of Economics and Statistics*, 1963, p. 375.

CHART 2. *Hours of Work of Production Workers in Manufacturing 1900–64*



SOURCES:
⊙ Series 1. Ethel B. Jones, "New Estimates of Hours of Work per Week and Hourly Earnings, 1900–57," *Review of Economics and Statistics*, 1963, p. 375.
⊡ Series 2. U.S. Bureau of Labor Statistics, *Employment and Earnings Statistics for the United States*, May 1963, p. 7–E, for 1900–62. For 1963–64, *Monthly Labor Review*, No. 9, September 1965.
• Series 3. Reproduction of Figure 1, "Nonagricultural Hours of Work, 1850–1964."

the collective bargaining agreements that followed the pattern established by that law. But the legislative and institutional record may simply be the transmission belt through which the labor force has reduced the average hours supplied as the real hourly wage has increased.[3]

The Cyclical Pattern

Superimposed on the long-run downward trend of the workweek is a distinct cyclical pattern. As demand changes, production can be adjusted through some combination of employment and hours changes. The initial response is likely to be primarily in additional hours. When the economy turns down, costly overtime hours can be eliminated quickly and work schedules can be reduced to conform to production needs. In mov-

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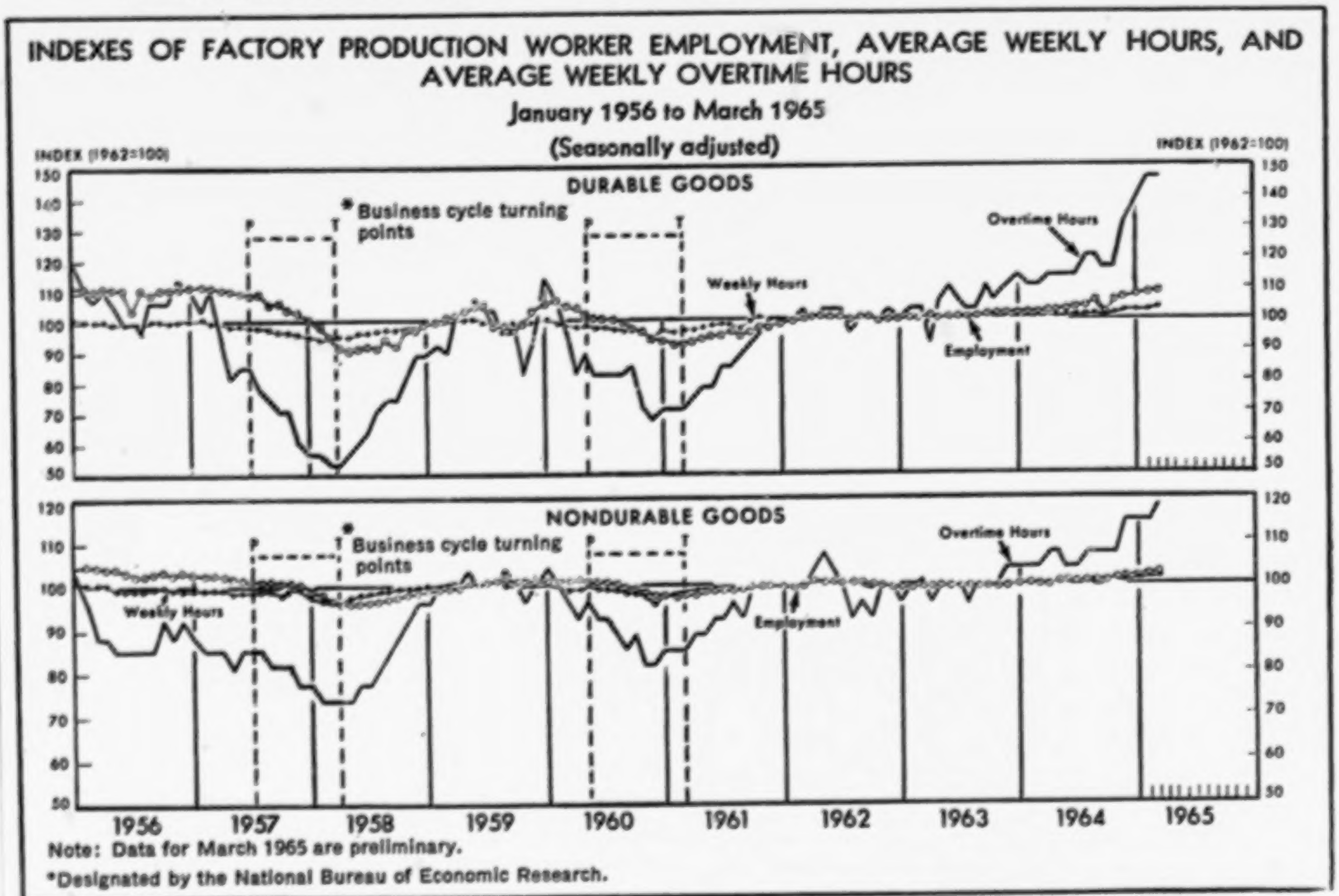
[3] It is generally believed that the supply curve of labor is backward sloping at some point, that less labor will be supplied at higher real wages. Evidence to support this view was reported by T. Aldrich Finegan, "Hours of Work in the United States, A Cross-Sectional Analysis," *Journal of Political Economy*, October 1962, pp. 452–470.

CHART 3. *Relative Movements in Weekly Hours, Overtime Hours, and Employment Since 1956*



SOURCE: J. Ross Wetzell, "Current Developments in Factory Overtime," *Monthly Report on The Labor Force*, April 1965, p. 17.

ing out of a recession trough, employers will move back to normal work schedules before employment is increased. As might be expected, overtime hours are even more sensitive than the workweek to economic activity. Chart 3, which appeared in an article by J. R. Wetzell[4] on current developments in factory overtime, shows the relative movements in weekly hours, overtime hours, and employment in relation to National Bureau of Economic Research turning points since 1956.

In the long recovery period since early 1961 the workweek for production workers in manufacturing increased steadily until the annual average for 1964 was as high as it had been in any year since 1945. This was true in spite of the fact that the unemployment rate in 1964 was substantially higher than in either 1955 or 1952 when the manufacturing workweek equaled the 1964 figure. Overtime hours in manufacturing climbed sharply at the beginning of the recovery, remained relatively steady until mid-1964, and then started to climb to record levels. The increase in the workweek and overtime hours received part of the blame for the fact that the unemployment rate declined very slowly as the economy continued its gradual recovery through 1964. It was argued that employers found it less costly to increase production by increasing the workweek and using overtime than by hiring new employees. How can we compare the present situation to past experience? One way is to compare the present overtime hours and workweek with the same figures for a year when the economy was functioning at about the same fraction of capacity. Using the unemployment rate as a measure of overall economic activity, 1964 appears to have a somewhat longer workweek and higher overtime hours than one would expect on the basis of past experience. The manufacturing workweek in 1950, when the unemployment rate was 5.3 percent, was 40.5 hours compared with 40.7 hours in 1964. The relationship between unemployment and the workweek is not very close in the postwar period (see charts 4 and 5) but the average hours of work for 1962, 1963, and 1964 were all substantially on the high side of the average postwar relation between aver-

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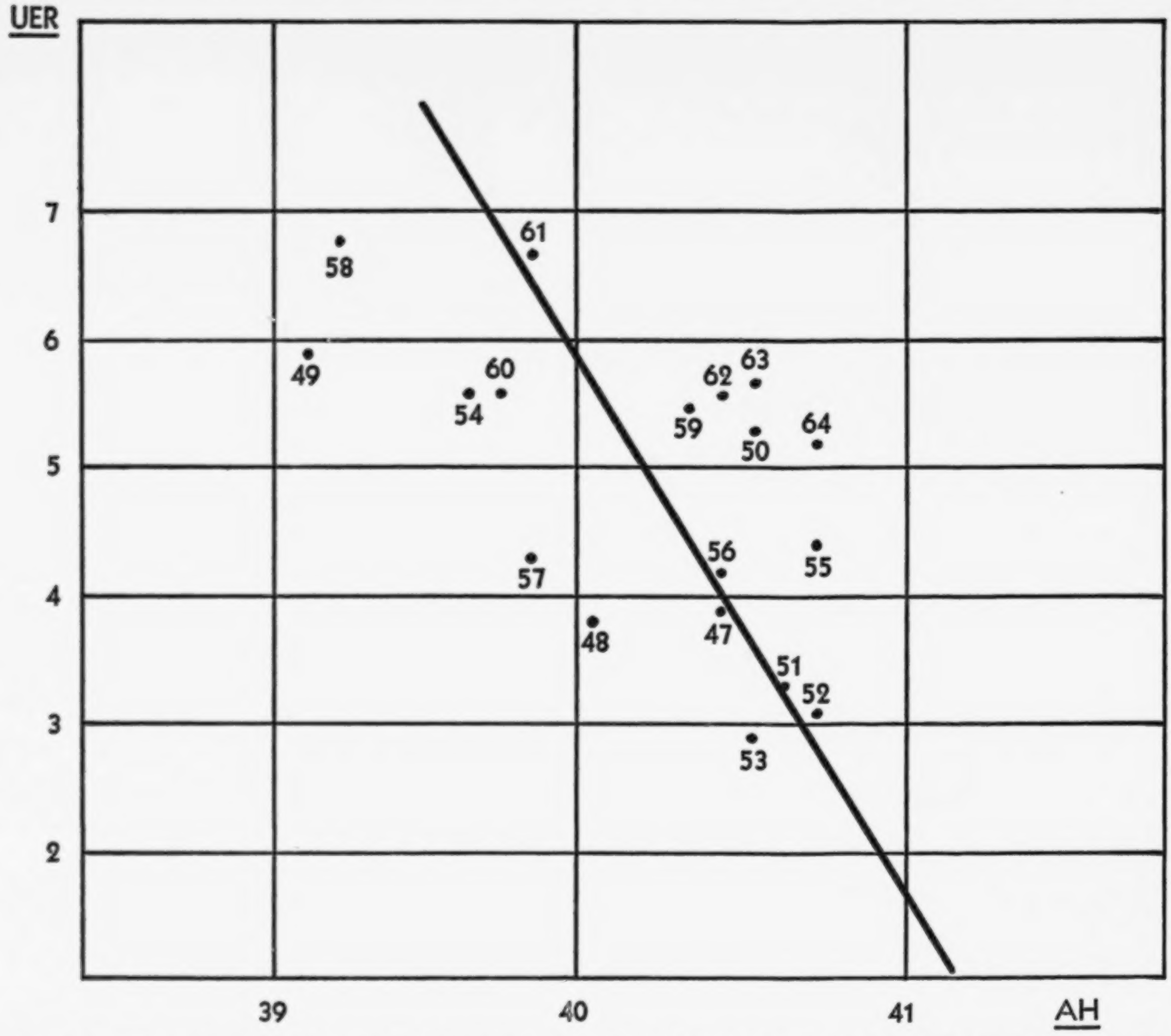
[4] J. Ross Wetzell, "Current Developments in Factory Overtime," *Monthly Report on the Labor Force*, April 1965, p. 17.

CHART 4. *Average Hours of Manufacturing Production Workers vs. Unemployment Rate, 1947–1964*



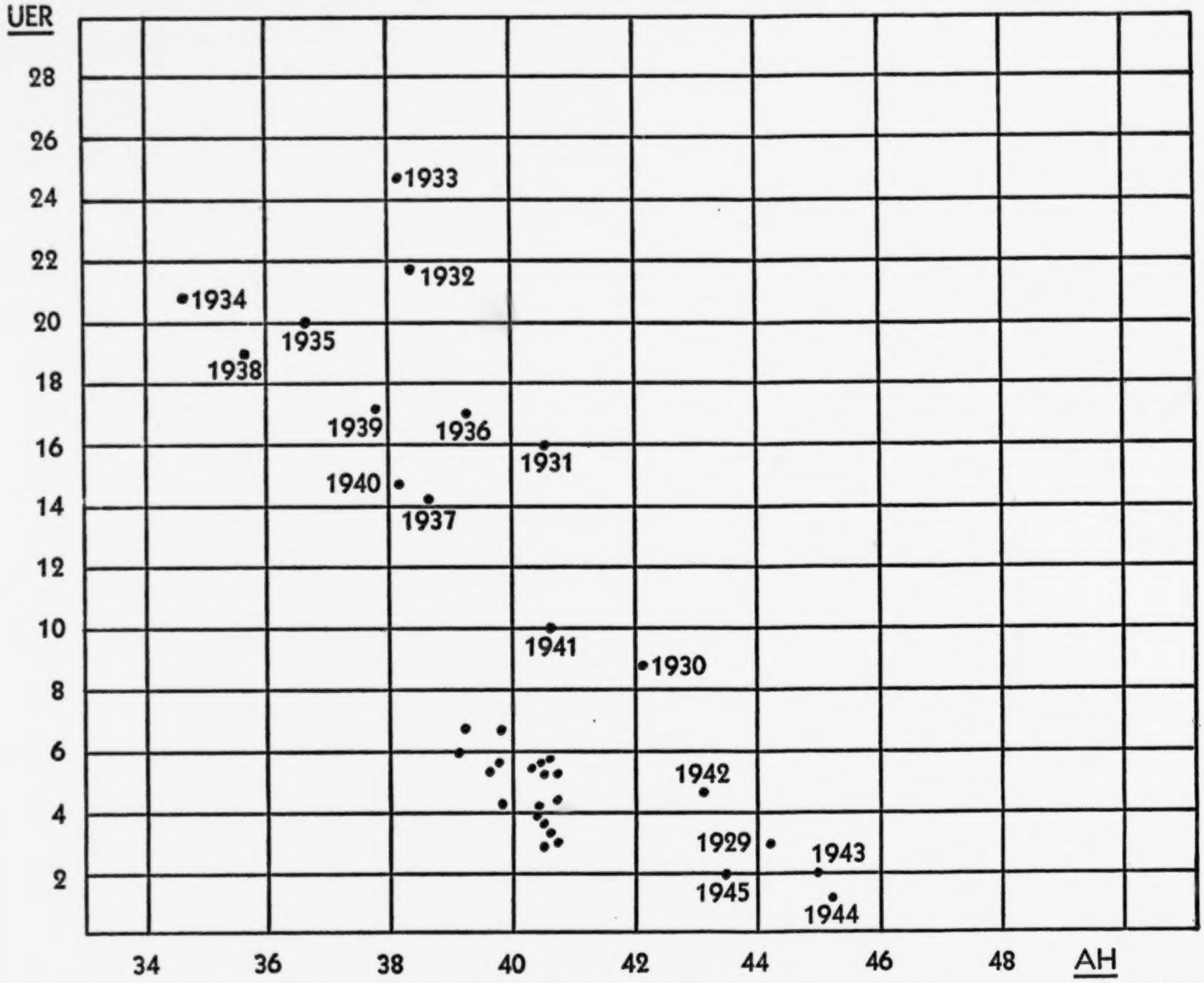
NOTE OF REGRESSION RESULTS: Adjusted coefficient of correlation equals .55; adjusted R squared equals .31.

SOURCES: UER: "Unemployment as Per Cent of Civilian Labor Force," from *Economic Report of the President,* January 1965, p. 214, Table B–21 (1961–64 include Alaska and Hawaii). AH: "Average Hours of Manufacturing Production Workers." See U.S. Bureau of Labor Statistics series, chart 2.

age hours and the unemployment rate. The three other years that show higher than average workweeks relative to their unemployment rates are all years in which the unemployment rate fell from a previous high. In fact, they represent all such years since 1948 (see chart 4).

The only postwar year in which the workweek did not fall when the unemployment rate increased substantially was 1961. From 1960–61, as the annual unemployment rate moved up from 5.6 percent to 6.7 percent, the workweek reversed the declining trend of the previous year. The monthly data show that average hours increased as the unemployment rate went up from 6.5 percent in January to 7.1 percent in May. The overtime hours show a similar pattern. The annual average for 1961 is the same as for 1960, and the monthly figures show that overtime hours started to increase at the beginning of 1961. In any event there seems to have been a shift in the relationship between unemployment rate and the workweek in 1961 which persisted through 1964. In

CHART 5. *Average Annual Hours of Manufacturing Production Workers vs. Annual Overall Unemployment Rate, 1929–64*



NOTE: Identification of unmarked points may be found in chart 4.

SOURCES: U.S. Bureau of Labor Statistics, *Employment and Earnings Statistics for the United States,* December 1964, and February, 1965.

the past, the process of adjustment has shifted this relationship back toward the average, but so far that has not happened in our present expansion.[5]

The concern that unemployment reduction was being hampered by overutilization of overtime was increased by a rapid acceleration in overtime use starting in August of 1964 and continuing into 1965. The March figure was up nearly a full hour from the previous year and was the highest figure for March since the data have been reported. However, a careful analysis of this upsurge by Wetzell[6] demonstrated that "the relative contribution of hours and employment to the change in gross man-hours was not significantly different in the August-to-March surge than in the earlier period of economic expansion. On the basis of these developments it may be concluded that the August-to-March overtime increase was *primarily* the result of a normal adjustment to the improvement in economic activity."

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[5] In his article cited above, Wetzell points out that average overtime has risen relative to production workers since 1965, and identifies industries in which the change has been most pronounced. This comparison, however, is inappropriate, and no valid conclusions can be drawn from it. Over long periods of time, because of shifts in demand and differential productivity changes, production worker employment in particular industries will change. A lower employment level in 1964 could represent the same utilization of capacity in an industry as a higher level of employment in 1965. A comparison of employment-overtime relationships would be more valid over a short span of time, such as from trough to peak in a single cycle. Intercycle comparisons would be more valid for aggregated data which average out shifts among industries, and for time periods in which employment changes have not been substantial. The same or higher levels of overtime in particular industries that show reduced employment do not by themselves demonstrate changes in employment or scheduling policies by these industries.

[6] Wetzell, *op. cit.,* pp. 17–22.

Another approach to the problem is to see whether in the current upswing the workweek and overtime hours have increased more rapidly relative to the decline in unemployment than in earlier recoveries. The evidence does not support this contention for the postwar period. In her paper "The Behavior of Employment 1961–1965," presented at a conference on the Last 5 Years: Economic Expansion and Persisting Unemployment in June 1965, Margaret Gordon points out, "The increase in hours of work in the early stages of the present upswing was slight, compared with previous upswings . . . in other words, an unusual increase in hours of work apparently did *not* play a role in accounting for the sluggishness of the increase in employment." From 1961 to 1962, a reduction of 1.1 points in the unemployment rate was associated with a .6 hour increase in the manufacturing workweek. The relative increase in the workweek in this period was substantially less than the comparable shifts in 1949–50, 1954–55, and 1958–59. However, for the period 1961 through 1964, it would appear that the increase in the workweek, relative to the reduction in unemployment, was greater than that from 1949 through 1953 and 1958 through 1960. These annual figures are very rough measures, but the pattern is consistent with the proposition that the present expansion appears to differ from earlier postwar periods in that as the recovery continued after the first year, the workweek seems not to have adjusted back toward the average, relative to the unemployment rate, as it did in earlier expansions.

The overtime series does not go back far enough to provide a strong independent test. However, the increase in overtime from 1961 to 1962 was less than would have been expected on the basis of the 1958–59 experience, and the increase to 3.1 hours of overtime in 1964 from 2.8 in 1963 is consistent with the 1958–59 pattern. Evidently the use of overtime relative to the unemployment rate has not declined as the recovery has progressed.

Employment and hours of work are the means by which the economy adjusts production to demand. It is reasonable to assume that adjustments in hours are more likely to be short-run adjustments with employment shifting in response to longer-run demand requirements. I constructed a simple model in which employment varies as if it were influenced by the current workweek and by all previous workweeks, with the influence of earlier periods decreasing geometrically. This assumes that as production increases both employment and average hours will increase, but that the change in employment will be influenced by previous changes in the workweek.

Using unadjusted monthly data I tested this model on 5-year periods from 1936 through February 1965. The results suggest that in the most recent period a smaller change in the current workweek is associated with a given change in employment than in the past, but that the lagged influence of hours on employment is smaller. Since I do not mean to imply causality, perhaps it would be better to say that in the most recent 5-year period, employment did not continue to increase after an initial increase in the workweek as much as it had in the past. Application of the model to recession and recovery periods provides additional evidence. In the period from July 1960 to January 1961, the workweek change, relative to a change in employment, was less than in comparable past periods, and the lagged relationship between the workweek and employment was substantially less than in the two previous recession periods. As employment fell, the workweek did not decline as rapidly as it had in earlier periods. This would permit a larger employment increase in the recovery phase to be associated with any given increase in the current workweek; or to reverse the relationship, it permitted a smaller increase in the workweek to be associated with a given increase in employment. However, the model does not demonstrate any substantial change in the relationship between hours and employment when the 1961–65 recovery is compared to similar periods since 1948. The higher-than-average hours relative to the unemployment rate in 1962–64 may be explained in large part by the unusually small reduction in the workweek in the 1960 recession.

Summary

On the basis of available evidence, what can we say about whether or not hours of work and overtime patterns have shifted relative to economic activity? It appears that the workweek is somewhat higher now than the level that would be expected on the basis of past experience. There seems to have been a shift in the hours-unemployment rate relationship in 1960–61 when the workweek was not reduced as much as might have been anticipated on the basis of past experience.[7] In addition, as the current expansion extended beyond the first year, there was no reduction in the manufacturing workweek or overtime use, as seems to have been the pattern in the past. This may be a function of the unprecedented length of the recovery, and what we are observing may simply be a continuing process of adjustment by em-

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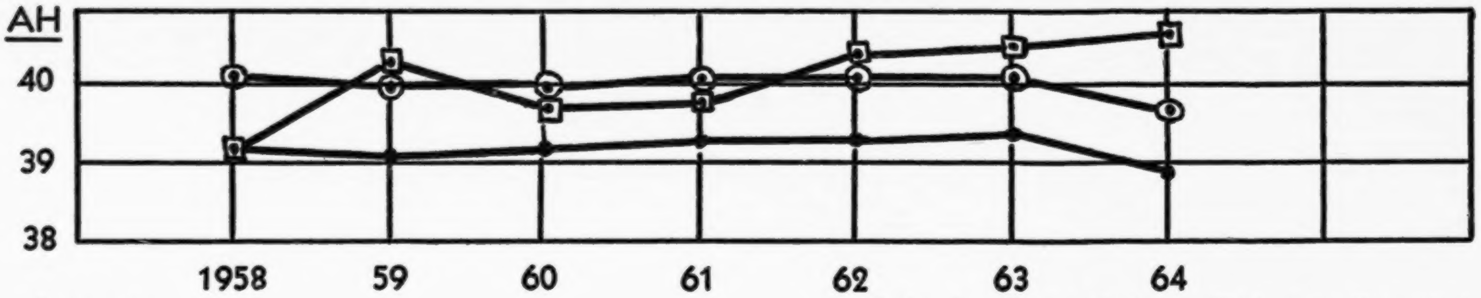
[7] I have no immediate explanation of the 1960–61 pattern. Perhaps the structure of demand reduction forced more of the adjustment burden on employment, or employers may have been under strong pressure to reduce payroll costs. A careful examination of the changes that took place in that period may suggest an answer, but it is beyond the scope of this paper.

CHART 6. *Hours of Work for Nonagricultural Persons, Nonagricultural Wage and Salary Workers, and Manufacturing Production Workers, 1958–64*



SOURCES:
⊙ Series 1. All Persons in Nonagricultural Industries. April 1965, p. A–25, table D–1. Earlier data from Report 1961–64 data from Special Labor Force Report No. 52, No. 14, April 1961, and Report No. 4, May 1960.
● Series 2. Wage and Salary Workers in Nonagricultural Industries, Special Labor Reports Nos. 52, 14, and 4, tables D–2.
⊡ Series 3. Manufacturing Production Workers, Bureau of Labor Statistics, see chart 2.

ployers who were not prepared for the expansion and who have not yet caught up with the economy.

It must be emphasized that the above analysis is based on the gross weekly hours of factory production workers, which include all hours paid for, including paid vacations and holidays. Actual hours worked would be somewhat lower than payroll hours, and would show some gradual decline in time as vacations have lengthened and holidays have increased. The average weekly hours in nonagricultural industries do not show any evidence of the shift that may have taken place in manufacturing. The average weekly hours in 1964 (May) were lower than in 1950 when the unemployment rate was 5.3 percent, and lower than in 1959 when the unemployment rate was somewhat higher. The average workweek fell for all employees in nonagricultural industries in 1964, and fell even more sharply for wage and salary employees (see chart 6). Here is some evidence that the economy may be adjusting the workweek back toward a longer-run figure and that the gradual downward trend may reassert itself.

The Impact of Part-Time Work

In recent years, particularly outside of manufacturing, the hours of work data may overstate the extent to which the long-run downward trend in the workweek has continued. As Henle pointed out,[8] "Since part-time workers have been forming a considerably higher portion of the labor force, the figures for all workers exaggerate the trend toward a shorter workweek." In 1955, voluntary part-time workers[9] made up about 8.3 percent[10] of all those employed in nonagricultural industries. By 1964, this figure had reached 11.7 percent. Sixty-five percent of this part-time working force is female. From 15 to 20 percent of women in the various age groups from 18 to 64 were voluntary part-time workers in 1964. A higher proportion of teenagers of both sexes (72 percent for boys and 77 percent for girls) are voluntary part-time workers, and a relatively high proportion of men and women over 65 (30.7 percent and 42.5 percent, respectively) are part of this voluntary part-time work force. The increasing importance of this part-time group is probably a complex function of the interaction of changes in industry, occupations, and labor force composition, as well as a response to changes in institutional and sociological patterns. There has been some increase in part-time workers in nondurable manufacturing, but the most pronounced changes have occurred in wholesale and retail trade where the part-time group, as a fraction of the total, has increased about 3 percentage points, and in the service industries where the part-time segment of the work force is about 2 percentage points higher since 1959. By occupation, the fraction of clerical and salesworkers who are voluntary part-time workers has increased about 2 and 3 percentage points, respectively, and about 9 percentage points among private household workers.

The average workweek for voluntary part-time workers has remained relatively constant at about 16.2 hours since 1959. But the increasing fraction of the work force in this category automatically tends to reduce the average number of hours worked in the economy. In fact, it is possible to calculate what would have happened to the average workweek if the average number of hours worked by part-time workers and full-time workers stayed exactly the same, and the proportions in these groups changed as they have between 1959 and 1964. From published data it was possible to compute the average hours for workers other than voluntary part-time workers in 1959. The average hours for these groups were then weighted by the fraction of the nonagricultural work force working part-time voluntarily, and all others. The projected average hours for 1964 computed this way is 39.1 hours compared to an actual workweek in nonagricultural industries in 1964 of 39.7 hours. In short, the shift to voluntary part-time work more than explains the reduction in the workweek from 1959 to 1964.

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[8] Peter Henle. "Recent Growth of Paid Leisure for U.S. Workers," *Monthly Labor Review*, March 1962.

[9] Workers who usually work part time and worked part time during the survey week for noneconomic reasons (e.g., did not want full-time work, too busy with school and housework).

[10] Seasonally adjusted monthly average for the months May–December, 1955.

Part of the increase in the relative importance of the voluntary work force is due to the fact that a larger fraction of workers in several age groups are working part-time voluntarily compared with 1959. However, a substantial part of the shift can be attributed simply to a shift in the age composition of the work force. The 1959 average hours of work by age and sex weighted by the number of workers in each age-sex category in 1964 produce a projected 1964 average workweek in nonagricultural industries of 39.8 hours, or a reduction of 0.2 from the 1959 average of 40.0. The actual reduction, as indicated above, was 0.3 to an average workweek of 39.7 hours.

Any apparent reduction in working hours in recent years is attributable in large part to the increased relative importance of industries and occupations in which part-time work is concentrated, and to the relative increase in the supply of workers in the age-sex categories that provide most of the part-time work. Further evidence of the effect of this shift can be obtained from a comparison of the average hours data for full-time workers to the average for all workers. For example, from 1948 (May) to 1963 the average weekly hours worked by wage and salary workers in nonagricultural industries went down from 41.1 to 39.4, a reduction of 1.7 hours. In contrast, the workweek for full-time workers was 44.2 hours in both periods. The full-time workweek data support the view that the hours of work in 1963 were higher relative to the unemployment rate than in previous years. The 45.0 hours average for all persons working full time in nonagricultural industries was higher than the figure for 1960, when the unemployment rate was slightly below the 1963 figure, and higher than the average for 1952 and 1956, when the unemployment rates were substantially below the 5.7 percent rate of 1963.

As we increase the normal period of schooling, as the labor force participation rate of women increases, and as retirement becomes more attractive for workers in their later years, we can expect the part-time work force to grow in relative importance. As this occurs it will become more and more important that the full-time and part-time components of our key labor-force indicators—employment, unemployment, wage rates, and hours of work—should be reported and analyzed separately.

For example, the overall unemployment rate could lead to an overestimation of unused capacity in a period when the part-time work force had increased in relative size, and aggregate industry employment figures could provide misleading evidence of the effects of minimum wage and overtime penalty legislation. Recently the Department of Labor has published more information about part-time workers, but further work is needed in the development and analysis of data concerning the full-time and part-time work forces.

Overtime Hours

In May of 1964 nearly 15¾ million wage and salary single-job holders worked 41 or more hours. They represented one out of every four single job holders. Over 7 million of them worked 49 hours or more in the survey week. These figures represent a tempting target for those who believe that overtime hours can be translated into jobs. Secretary of Labor Wirtz has stated that:

> the evidence is clear that the 40-hour workweek has become a base for computation for overtime pay rather than an accepted workweek goal, that overtime has become an integral part of the wage-hour structure, and that employers schedule overtime at time and one-half, not for emergencies but for day-to-day operations, primarily because it is cheaper than hirhiring additional workers.
>
> A double-time provision will create jobs in industries in which the effectiveness of the time and one-half provision for overtime—as a deterrent to long hours—has disappeared.[11]

In contrast, Joseph Garbarino concluded, "On the basis of the available data . . . for manufacturing as a whole there is little evidence that working overtime has been substituted for adding employees in recent years to any greater extent than was the practice in the mid-50's."[12] As I have indicated above, the evidence is mixed, but the recent high levels of overtime are primarily due to the pattern of overall economic activity; there is little basis at this time for concluding that a basic shift has taken place in the relative use of overtime and employment to satisfy production needs.

Whether or not there has been a shift, it is true that the relative costs of overtime hours in comparison with the costs of available alternatives determine the amount of overtime scheduled at any point of time. However, the alternatives are not limited to the hiring of new employees, and the relevant comparative costs are not just the dollar costs associated with new hires. In many cases the real alternatives to overtime use are curtailment of production or extensive capital expenditures. The relevant costs might include loss of customers, bad public relations, inability to recruit workers in short supply, and employee resentment of fluctuating employment levels.

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[11] Hearings before the Select Subcommittee on Labor, House of Repr., 88th Cong., 2d Sess. on H.R. 1680, H.R. 9802, Part 2, p. 867.

[12] Joseph W. Garbarino, "Fringe Benefits and Overtime as Barriers to Expanding Employment," *Industrial and Labor Relations Review*, April 1964.

Some insight into these issues may be obtained by reviewing the major factors considered by employers in scheduling overtime rather than hiring additional workers. On the basis of an informal survey taken by Department of Labor representatives, Secretary Wirtz listed the following factors:[13]

> 1. Availability of skilled labor.
> 2. Availability of additional equipment.
> 3. Cost of training and length of training period.
> 4. Reduction in output of experienced workers.
> 5. Adverse effects of subsequent layoffs on unemployment experience ratings.
> 6. Employees' willingness to take a job of limited duration.
> 7. Cost of fringe benefits—relatively few respondents pointed to this as a cost deterrent in hiring new workers. Relatively few of the firms contacted seemed to have very elaborate or careful cost analyses on which to base decisions on relative costs of overtime and fringe benefits.
> 8. Expected duration of increased demand.

Employers who scheduled overtime hours were faced with increased production needs that were of short or uncertain duration, whereas employers who hired new workers expected a long period of increased production. This factor alone could explain a great deal of the increased use of overtime during the current expansion. The economy has groped its way forward slowly and hesitatingly since early 1961. Uncertainty about the strength and duration of the expansion would increase the apparent risk of hiring new workers and lead to overtime scheduling as the safest way to make "temporary" adjustments.

Some overtime was attributed to the shortage of skilled workers, and employers who succeeded in avoiding overtime reported the availability of trained workers and workers on layoff, or they were able to increase production with relatively low-skilled workers.

Some employers explained their use of overtime by the requirements of balancing production, "especially in complicated assembly operations, where some departments are ahead or behind others. The increased production may not warrant adding workers for a full workweek." In contrast, employers with unused equipment were more likely to increase production by increasing employment. Additional reasons for scheduling overtime reported by Secretary Wirtz included:[14]

> In the case of cost-plus defense contracts, premium overtime was said not to be deterrent even if it were to exceed time-and-one-half.
>
> The need to speed up maintenance work and thus reduce lost production time.
>
> Increased income for employees encouraged by unions or by the employers as a means of attracting employees in a tight labor market.
>
> Weather conditions in some operations.
>
> Difficulty of finding workers to work a late shift.

In addition he reported the following factors as influencing employers to hire new workers rather than schedule overtime:

> Union pressure to call back laid-off workers.
>
> Reduced productivity on overtime.
>
> Company policy against overtime except in emergencies.
>
> Safety.
>
> Costs of overtime—relatively few respondents specifically stated that the existing time-and-one-half requirement was or was not a deterrent to work overtime.

It is apparent from these factors that in many cases the decision to schedule overtime rather than hire additional workers is only marginally related to the size of the overtime penalty rate, and that frequently the only realistic short-run alternative to the use of overtime would be to forego production.

Because of its extensive use of overtime work, the automobile industry has been cited frequently to illustrate the need to reduce overtime hours. In his statement before the Senate Subcommittee on Labor, John S. Bugas, vice president, Ford Motor Company, presented a detailed explanation of the use of overtime in his industry.[15] He classified overtime use as follows:

> 1. Emergency overtime, caused by the need for emergency repairs, temporary production bottlenecks, and production losses incurred by parts and material shortages, employees' absenteeism, strikes, and weather conditions.
>
> 2. Tooling periods and model changeover. He asserts that in this period the industry employs as many craftsmen as are available to complete the changeover as quickly as possible. In this case, the overtime penalty gives the employers a chance to recruit needed workers by promising overtime work.
>
> 3. Cyclical overtime. Sales of the industry have fluctuated widely during the postwar period, and a considerable amount of overtime has been required because of the company's failure to make accurate predictions of demand. He estimates that major facility programs require a lead time extending beyond 2 years and that "year-to-year changes in demand occur much more rapidly than the industry's ability to effect changes in facilities." As he points out, capital expenditures must take into consideration the risk of overtime and down time at some future date.
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> 4. Seasonal overtime. On the average, the industry must change its quarterly production requirements by a 10-percent increase from the first to the

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[13] Hearings Before the General Subcommittee on Labor and Select Subcommittee on Labor, House of Repr., 88th Cong., 2d Sess. on H.R. 1680 and H.R. 9802, Part 1, p. 19.

[14] *Ibid.*

[15] Statement of John S. Bugas, vice president, Ford Motor Company, Hearings before the Subcommittee on Labor of the Committee on Labor and Public Welfare, U.S. Sen., 89th Congress, 1st Sess., on Amendments to the Fair Labor Standards Act, July 8, 1965.

> second quarter, a 29-percent decrease in the third quarter, a 40-percent rise in the fourth quarter, and then a 9-percent drop in the first quarter. Mr. Bugas asserts that "Experience has shown that scheduling regular employees overtime is by far the most efficient and desirable means of meeting these production requirements from the standpoint of the companies, their employees, and the communities where they live." As is the case of cyclical overtime, Mr. Bugas argues that it would clearly be uneconomical to plan facilities to meet seasonal highs, and that further, the employers are severely restricted in their ability to adjust production by adding or laying off employees. On a given assembly line it is extremely difficult to change the ratio of men to equipment or to add additional men to the line once the job of balancing the tasks assigned to each work station has been accomplished.
>
> 5. Shifts in customer preference. In a manner similar to cyclical and seasonal fluctuations, unanticipated shifts in customer tastes require the use of overtime to satisfy demand for a particular model. Mr. Bugas argues that overtime hours are necessary if production requirements are to be met with existing facilities.

It is clear that the automobile industry representatives believe that a substantial part of the overtime hours utilized by the industry are unavoidable. In his testimony, Theodore Yntema, vice president, Ford Motor Company, described unavoidable overtime as situations where "feasible operating alternatives or an adequate supply of labor or manufacturing facilities to meet the demand in time required" are not available.[16] In the long run, he argues, the industry attempts to correct situations that might produce overtime schedules, but in the short run the automobile companies have no reasonable alternative. In partial support of this contention, Mr. Bugas pointed out that a survey of the automobile industry indicated that 35 percent of the premium hours paid over 48 per week and 22 percent of the premium hours paid over 45 per week were compensated at double time. He and other industry spokesmen argue that they already have sufficient incentive to avoid overtime where it is possible to do so under the special circumstances of the industry.

In contrast, Leonard Woodcock, vice president of the UAW, argues that much of the overtime scheduled by automobile employers is avoidable. In his testimony at the 1964 Hearings,[17] he provided examples of firms that had scheduled assembly workers for 18 or more overtime hours per week over extended periods. He denied that this regularly scheduled overtime was caused by emergencies or by shortages of skilled workers. He pointed out that none of the plants he referred to was operating multiple shifts, and argued that the overtime could have been translated into a substantial number of additional jobs. Woodcock asserts that the overtime penalty rate is insufficient to discourage the scheduling of overtime. He argues that excessive overtime could be avoided by the use of multiple shift operations, varying the speed of the assemblyline and the number of workers employed to man the line, and by balancing production among various company plants. He quotes a corporation internal bulletin which states in part:

> The practice of recalling laid-off employees for a short-term employment must be avoided as much as possible because it adversely affects the corporate image in the community and results in increased costs. Increased costs include such items as payroll taxes, insurance premium and benefit charges, SUB and State Unemployment Compensation benefit charges.
>
> It is highly recommended that each request for temporary or short-term help be reviewed closely and discussed thoroughly with the view that hiring of short-term employees should be avoided wherever possible. Serious consideration should be given the advisability of working present employees overtime for a limited period of time rather than recalling other employees for short-term employment.

The term "unavoidable" is, of course, relative. At some cost an employer will have to choose the next best alternative to scheduling overtime. It is undoubtedly true that some of the overtime cited by Woodcock could have been translated into increased employment at some cost. It would take a special study of the automobile industry to evaluate the actual costs of the adjustments he suggests. However, it is apparent that some of his remedies could be extremely costly. For example, he recognizes that varying the speed and manning of the production line in response to shifting production requirements would require a reapportionment of individual work tasks. Although, as he says, this is not impossible, it would undoubtedly be quite costly to make such changes with any frequency. The learning and routinization of individual tasks are important factors in the efficiency of a production line. Disruption of that routine would necessarily cut substantially into efficiency. The feasibility of translating an average of 18 hours a week of overtime into a second shift would depend upon the capital-labor ratio required for production. Under the assumption that the increased production could be anticipated and scheduled over some period of time, would it be possible and economical to operate one-third of the plant for a second shift? Once again, the answer cannot be given without a detailed study of the industry, but it is certainly not obvious that the overtime hours could necessarily be translated into increased employment without increasing production costs substantially.

The company memorandum cited by Mr. Woodcock lists an adverse corporate image as one of the effects of providing short-term employment. This position is consistent with Mr. Yntema's statement that the industry has been trying to provide stable employment and high annual earnings for its employees, and that in the auto industry employees have been able to balance good years with overtime against bad years when workers may be on layoff for substantial periods. Mr. Woodcock strongly denies that the UAW approves of extensive overtime as an appropriate means of making up for short workweeks, and he provides examples of local unions protesting the scheduling of overtime with men on layoff. However, one of the purposes and presumably one of the effects of the SUB program negotiated by the union was to force the employers to smooth out the production of automobiles over the year. UAW agreements that provide 50 to 65 percent of the regular rate for hours between 40 and the smaller number actually worked make it fairly expensive to hire an employee for a short week. The union has helped to make it more costly to provide short-term employment, and it may be that the employers have found that increased employment stability and opportunities for overtime work are now important elements in their manpower policies.

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[16] Hearings Before the General Subcommittee on Labor and Select Subcommittee on Labor, *op. cit.*, Part 1, p. 214.

[17] Hearings Before the Select Subcommittee on Labor, *op. cit.*, Part 2, p. 779.

Although it may be true that under some circumstances hiring for short periods is more expensive than scheduling overtime and that some decisions could be reversed by a higher overtime penalty, it would appear that only a small fraction of overtime hours would be in that category. Except in the most extreme cases, the hourly cost of a steadily employed regular employee would be less than the cost of overtime. In a recession period employers can be expected to cut costs as closely as possible and to adjust their labor force to production requirements. In spite of this, in 1958, when the unemployment rate in the durable goods sector was 10.5 percent, durable goods production workers worked an average of 1.9 hours overtime each week. In nondurable manufacturing, the unemployment rate was 7.6 percent, and yet the average overtime was 2.2 hours. These figures may reflect some regularly scheduled overtime, but I suggest they indicate that even in a recession period a substantial level of overtime is required by absenteeism, day-to-day changes in production requirements, and emergency situations that cannot be handled in any other way within reasonable cost limits.

In the Labor Department survey cited by Secretary Wirtz and in the testimony before congressional committees, overtime hours were frequently attributed by employers to fluctuations in production requirements. In many cases, the magnitude or even the direction of these changes are unanticipated, and they lead to overtime scheduling by employers who try to avoid the high costs of hiring people for very short or uncertain periods of time. Some support for the assertions that overtime is caused by changes in production levels is found in the material submitted by Secretary Wirtz to the House Subcommittee on Labor.[18] He provided data on employment, average overtime hours, and average weekly hours for the 25 establishments with the highest overtime hours and the 25 with the lowest overtime hours in 19 industries. If overtime is attributable, at least in part, to variations in production requirements, the high overtime establishments in each industry would show a higher variance in the average workweek than would their low overtime counterparts. In all 19 industries for which data were presented the workweek varied more over the year in the 25 high overtime establishments than in the 25 low overtime establishments as measured by the relative range $\left(\frac{\text{total range}}{\text{mean}}\right)$. As measured by the relative interquartile range $\left(\frac{\text{interquartile range}}{\text{mean}}\right)$, which eliminates the extremes, the same inequality in workweek variance was found in 15 of the industries. These comparisons support the assertions that overtime scheduling is associated with fluctuating production requirements.

Unfortunately the testimony before Congressional committees tends to be self-serving. At the Hours of Work Hearings, employer representatives were obviously anxious to demonstrate that overtime hours are largely unavoidable and that increasing the overtime penalty rate would not increase employment. However, some of the detailed cases presented in the testimony provide some insight into the variety of situations under which overtime is worked. For example, Carl H. Hageman, representing the Manufacturing Chemists Association, provided four examples of the causes of overtime work supplied by four member companies of his organization.[19] At one company, 55 percent of the annual overtime resulted from absenteeism and emergency maintenance, and 45 percent from surges in demand of less than 2 months. Another large company reported the following distribution of overtime for 1963:

11 percent	attributable to absenteeism.
40 percent	to maintenance.
18 percent	to unanticipated and rush orders.
31 percent	to miscellaneous causes, such as weather, schedule changes, process problems, and premium pay for a day worked in a holiday week.

A third company with about 3,300 hourly employees who averaged 1.2 overtime hours per week estimated that 90 percent of the overtime was caused by absenteeism and breakdown. The fourth company attributed 50 percent of its overtime to absenteeism and other emergency shift coverage,

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[18] Hearings Before the Select Subcommittee on Labor, *op. cit.*, Part 2, p. 869.

[19] Hearings Before the General Subcommittee on Labor and Select Subcommittee on Labor, *op. cit.*, Part 1, p. 150.

28 percent to emergency maintenance, 15 percent to rush orders, and only 7 percent to scheduled overtime. Although there is no consistent pattern and there is no reason to believe that examples of this kind are representative, they serve to illustrate the fact that a substantial amount of overtime is, in a realistic sense, unavoidable, particularly in the short run.

Garbarino found that industries differ substantially in the amount of annual overtime worked and that these differences are stable over time. He attributed the overtime pattern (ignoring emergency situations) to the "technological characteristics of production, the character of product demand, and, not the least important, to the customary working practices developed over the years to meet personal, company, and union pressures and other characteristics of the labor market."[20]

In particular industries and in the overall economy, overtime use is a response to the economic and institutional environment. A review of the conditions that lead to overtime scheduling indicates to this author that, at least in the short run, overtime scheduling is frequently the only realistic alternative available to employers if they are to fulfill their production requirements.

Penalty Rates as a Deterrent

It has frequently been asserted by proponents of a higher overtime penalty rate that the time-and-a-half provision for overtime no longer serves as an effective deterrent. This argument assumes that the gradual increase in the cost of fringe benefits, particularly those that are employee rather than hours-of-work costs, have reached a point where in many cases it is now less expensive to work overtime at the 50-percent penalty rate than to hire a new employee.

It is doubtful that the growth of fringe costs alone would produce this result. Garbarino tested the effects of fringe costs and concluded, "When the logic of the technique is made explicit and the empirical data analyzed more carefully the cost of overtime is found to exceed fringe costs in all manufacturing, and the absolute dollar differential between the two has been increasing until recently."[21] His admittedly rough calculations show that, in the steel industry and in General Motors, fringe costs were substantially below the cost of overtime in 1960, and the difference had increased since 1947. However, as he goes on to point out, fringe costs represent only a fraction of turnover cost.

One of the key costs of hiring employees for short periods of time is the resulting increase in State unemployment insurance taxes under experience rating systems. Under the assumption that the use of short-time employees, rather than overtime, would move an employer up from a relatively low to a very high unemployment insurance tax rate, the costs of short-time employment can be shown to be higher than the use of overtime.

The calculations presented by Secretary Wirtz to the House Subcommittee on Labor in 1964 demonstrated the relative importance of unemployment insurance taxes and SUB contributions in the cost of short-term employment. In one of the examples used for illustration, the hourly cost of hiring a worker for 1,000 hours in a motor vehicles plant ranged from $3.78, assuming that SUB contributions and unemployment insurance taxes would not be affected, to $4.71, assuming that the layoff of workers hired for the marginal hours would result in resumption of suspended SUB contributions and that the unemployment insurance rating would be shifted from the most to the least favorable classification. Only in the latter case would the cost of increasing employment to meet the additional production requirements be greater than the cost of an equivalent amount of overtime.

Using a somewhat different approach, Bugas[22] presented a table showing the costs of wages and related fringe benefits of new hires versus the cost of working overtime for periods from 1 to 12 months. His calculations included as a related fringe benefit the total amount of unemployment compensation the employee would be entitled to at the end of the month for which the calculation was made. Under these assumptions, and largely because of the costs attributed to State unemployment insurance, it becomes more expensive to hire a new employee if he is expected to work more than 7 months but less than 11. Since these calculations did not include hiring, training, or other turnover costs, it is apparent that on a straight dollar costs basis it might very well be cheaper to work overtime than to hire a new employee for less than a year, even if no other considerations were involved.

However, just as there usually is a waiting period for State unemployment insurance, most new employees have to work a minimum period of time before they are covered by fringe benefits. As a result, if Bugas' assumptions are reasonable, the cost of private and public fringe benefits are unlikely to be an important factor in the decision to hire new employees for very short periods of time. If the skill requirements are low, so that training costs are not significant, the turnover costs might not be a significant deterrent to temporary employment.

Analysis of the type presented above may substantially overstate the cost of increasing employment, since it assumes that the employee to be added to the payroll is a new hire as far as fringes are concerned, rather than an employee recalled from layoff, who already represents a fringe cost. In the latter case, as R. Conrad Cooper, executive vice president, United States Steel Corporation, pointed out in his testimony, an employer would save unemployment benetfis as well as the overtime penalty by recalling employees on layoff rather than scheduling overtime hours.[23]

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[20] Garbarino, *op. cit.*, p. 430.

[21] *Ibid.*, p. 438.

[22] Statement Before the Subcommittee on Labor of the Committee on Labor and Public Welfare, *op. cit.*

On the basis of available evidence it seems unlikely that increases in fringe benefits are significantly related to any change in the use of overtime hours that may have occurred in the past few years. Under some circumstances it may be less expensive to schedule overtime than to hire employees for relatively short periods of time, but there is little evidence that total "turnover costs" have increased more rapidly in the last decade than the wage rates on which overtime penalties are based. There is no data on the amount of overtime that is "unavoidable." However, the use of substantial amounts of overtime in recession periods, and the fact that in many of the circumstances that lead to overtime increasing employment is not a practical short-run alternative, warrant a presumption that an increase in the overtime penalty rate would have very little short-run impact on employment. In particular industries an increase in the marginal cost of overtime scheduling might lead to an increase in employment, but such a conclusion should be based on detailed industry studies of overtime experience.

In attempting to increase employment opportunities, serious consideration should be given to changing public and private policies that discourage or raise the costs of employment as well as to the possibility of making overtime less attractive. Increasing the overtime penalty rate would undoubtedly cut down on the amount of overtime scheduled. But as long as the alternative costs are high, there is little reason to expect a parallel increase in employment, at least in the short run.[24]

Effects of the FLSA

In assessing the possible effect on overtime hours of an increase in the overtime penalty rate, it seems appropriate to raise the question of the effectiveness of the overtime penalty rates established by the Fair Labor Standards Act in 1938. It is somewhat embarrassing to have to admit that it is virtually impossible to demonstrate that the Fair Labor Standards Act has had a substantial effect on overtime hours worked or on the average workweek. All the evidence available is indirect. In 1938, when the Fair Labor Standards Act was passed, the average workweek was substantially below the 40-hour standard which was not to take effect until 1940. The workweek started to increase in 1938 and continued to increase for 6 years after the Fair Labor Standards Act was passed. Indeed, the clearest effect of the overtime penalty rates established by the law was to provide an effective means of attracting workers to war plants without increasing base rates. In many industries the pattern set in the war years has continued, and overtime hours are used to attract and reward employees. The continuing problem, shared by unions and management, of trying to allocate available overtime equitably among employees provides work opportunities for many arbitrators.

But where is the evidence for the effectiveness of the Fair Labor Standards Act in reducing the workweek and increasing employment opportunities? The great majority of collective bargaining agreements for production workers call for a 40-hour workweek, and the 40-hour week has been standard in most industries during the postwar period. However, the 40-hour week is consistent with the long-run downward trend of the workweek. The three shift operations developed during the war, the increase in real wages, and the pressures of collective bargaining probably would have led to the same or a similar workweek in the absence of the law. But that is all conjecture, and the fact is, we simply do not know to what extent the act resulted in a shorter workweek.

However, the data on the proportion of workers who receive premium pay for their overtime hours[25] provide some evidence for the impact of the overtime penalty on the scheduling of overtime.[26] Of the 15.7 million workers who worked 41 hours or more at one job in May 1964, only 30.8 percent received premium pay. And only about 25 percent of wage and salary workers who usually worked 41 hours or more receive premium pay, whereas 56.4 percent of those who did not *usually* work overtime received premium pay for their extra hours.

A rough approximation would be that about 50 percent of wage and salary employees are covered by the Fair Labor Standards Act. A substantially larger number would be entitled to overtime premium pay because of coverage by State laws or collective bargaining contracts. The fact that only one out of three employees who worked overtime in May 1964 received premium pay is consistent with the proposition that the penalty rate discourages the use of overtime that would incur penalty payments. This conclusion is further supported by the fact that of those workers who usually worked 41 hours or more only 25.2 percent received premium pay, suggesting that overtime penalty rates have discouraged the use of overtime on a regular basis in industries covered by legal or contractual penalty pay requirements. However, the evidence is far from conclusive, since there may be factors other than penalty payments that lead to these differences. The circumstances that require overtime may be more prevalent in the uncovered sectors of the economy.

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[23] In a paper presented at a Conference on Unemployment and the American Economy, June 16, 1965, Professor Albert Rees points out that "All unemployment insurance taxes in most States were paid on the first 1,587 straight time hours of annual employment; at 1964 levels of earnings, all such taxes in most States were paid on the 1,230 straight time hours of annual employment. It is in this sense that overtime costs have been falling relative to hiring costs."

[24] Garbarino concludes, "Popular discussion almost certainly underestimates the overall reduction that would occur, overestimates the number of jobs that would be created, and underestimates the time that the latter adjustment would take." Garbarino, *op. cit.*, p. 432.

[25] Since premium pay for overtime hours may be received under private agreements by employees not covered by the law, the aggregate figures serve only as a very rough approximation.

[26] James R. Wetzel, "Long Hours and Premium Pay," *Special Labor Force Report* No. 57, U.S. Department of Labor.

There is another source of evidence on the effectiveness of penalty overtime rates. The 1961 amendments to the Fair Labor Standards Act required that, effective September 1963, premium payments of time and one-half the regular rate of pay be paid for hours of work over 44 hours per week in covered retail establishments. The overtime penalty was applied after 42 hours, effective September 1964, and after 40 hours, effective September 1965. The Wage and Hours and Public Contracts Division of the Labor Department has published the results of nationwide surveys, conducted in June 1962 and again in June 1964, designed to test the impact of the law.[27] Another survey was made in the summer of 1965, but these data were not available when this was written.

What do the data show? Clarence Lundquist, Administrator of the Wage and Hour and Public Contracts Division, told the House Labor Subcommittee in 1964 that he did not believe the impact of the extension of the FLSA hours regulations to retail establishments would be very great. He pointed out that in June 1962 only 14 percent of the 2.4 million employees in covered retail establishments worked 45 hours or more, and these figures included gasoline service employees who are exempt from the overtime regulations. He predicted that the largest impact would be in nonmetropolitan areas and in the South.

The 1964 survey showed a modest reduction from about 12 to 10 percent of the fraction of covered employees working more than 44 hours a week, and Mr. Lundquist's predictions of the areas of maximum impact turned out to be accurate. In nonmetropolitan areas, the proportions working more than 44 hours declined from 18 to 14 percent, and in the South the reduction was from 17 to 13 percent. The reduction in hours occurred in all sections of the retail industry except furniture, home furnishings, and equipment, which use substantial commission payments, and in the exempt gasoline service station sector. In contrast to the reduction in hours among covered retail establishments, a sample taken in selected nonmetropolitan areas of the South shows no pattern of reduced hours among nonsubject retail establishments.

A more significant comparison is the experience before and after the change of establishments in which one or more employees worked more than 44 hours a week in June 1962. As might be expected, these establishments show a somewhat greater average decrease in the fraction of the work force working over 44 hours. The law seems to have had a particularly strong effect on drug store employees, particularly in nonmetropolitan Southern areas. In nonmetropolitan areas, the proportion of drug store employees working more than 44 hours declined from 28 percent to 16 percent, with a similar shift in the South.

Although in general there was an increase in the percentage of employees working exactly 44 hours, the reduction in employment over 44 hours was balanced to a considerable degree by an increase in the proportion working under 44 hours, including in many cases a substantial increase in part-time work. The highest relative concentrations of high-hour workers were in establishments where the average wage was under $1.50, and it was in this group that the greatest shifts took place. In some of the low-wage groups, particularly in food establishments, the substantial reduction in the proportion of employees working long hours was balanced in large part by an increase in the use of part-time workers.

The survey data indicate that extension of the law helped to reduce the workweek and overtime hours in covered retail establishments. However, there is little indication that the hours reduction led to an increase in employment. Employment in covered retail establishments increased by about 4 percent from June 1962 to June 1964. But in the same period total employment in retail trade increased by 5½ percent, while overall nonagricultural employment increased 4½ percent. Thus the aggregate data do not support the view that the hours reduction increased employment in covered establishments. In fact, employment decreased in four of the eight individual lines of retail trade. In five of the nonmetropolitan Southern areas for which data were obtained on a matched basis in 1962 and 1964, employment increased in conjunction with a decrease in the proportion of employees working over 44 hours. However, these five areas had a total employment in subject establishments in 1962 of only 67,000 employees. Examination of the employment experience of establishments that had one or more employees working more than 44 hours a week in June of 1962 shows a 1-percent increase in employment over the 2-year period. Except for the furniture section, the retail industry showed an increase in the proportion of part-time work in covered establishments, which was most striking in those sections of the industry and in those geographical areas where the law had its greatest effect.

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[27] *An Evaluation of the Minimum Wage and Maximum Hours Standards of the Fair Labor Standards Act*, U.S. Department of Labor, January 1965.

In overall retail trade, the increase in employment of employees with schedules below 40 hours a week is substantially greater, almost twice as much, as the overall increase in employment. The increase in part-time workers (under 35 hours a week) is almost as large as the overall increase in employment, and in the food sector the increase in part-time workers is greater than the increase in employment. If an increase in regular employment was one of the objectives of applying the overtime penalty provisions of the Fair Labor Standards Act to the retail industry, the evidence available to date indicates that the policy has been a failure. Indeed, in some areas and sectors of the industry there may have been a loss of full-time employment as part-time workers were substituted to fill the needs of store managers. Admittedly, the evidence is very scanty and the results of the more recent survey may provide additional insight into the situation.

The retail trade experience seems to support the proposition stated earlier that the overtime penalty has a greater potential for reducing overtime hours than for creating full-time employment.

In evaluating proposals to reduce the amount of overtime work, some thought should be given to the interests of workers who are currently using overtime work to supplement their incomes. This might be an academic welfare problem if the trade-off was that of high incomes for skilled, highly paid employees balanced against the prospects for increasing employment opportunities. However, a great deal of overtime is worked by very low-paid employees for whom a reduction in work opportunities would represent a substantial cut in income. The retail trade survey provided some evidence on this point. The 1962 survey showed that establishments with average hourly wage rates of less than $1.50 had the largest proportion of employees working more than 44 hours. In food establishments and drug stores with average hourly rates of less than $1.50 an hour, and in which some employees worked more than 44 hours, over 30 percent of the employees worked over 44 hours a week. And it was these low-paying establishments with the greatest proportion of workers working long hours in 1962 that showed the greatest decline between 1962 and 1964 in the proportion of employees working more than 44 hours. It would appear that the law reduced the earning opportunities of low-paid workers as part-time work replaced full-time work and overtime hours.

The evidence on whether overtime is worked primarily by low- or high-paid employees is necessarily mixed, since overtime is worked for such different reasons. Overtime caused by skill shortages is likely to lead to higher incomes for already high-paid workers. However, when overtime is related to fluctuations in production and employees are able to exercise choice about whether or not they will work overtime, the desire of lower-paid employees to increase their incomes will become more important. A March 1964 survey of manufacturing[28] showed that, on the average, straight-time earnings of employees working overtime were 9 cents an hour less than the average for those on a 40-hour week, and only 5 percent of those working overtime were paid less than $1.30 an hour. But an industry analysis shows substantial variance. For example, in grain mill products, the average pay of employees working 40 hours a week was 25 cents an hour more than those who worked overtime. In contrast, in metalworking machinery and equipment, those working overtime had average straight time rates of 7 cents an hour more than those on a 40-hour week. The largest amount of overtime per employee and per employee working overtime was in the nonelectrical machinery industry which had the second highest average hourly earnings. However, the next highest overtime hours per employee and per employee working overtime was in the textile mills products industry which had the *lowest* average hourly earnings. In wholesale trade,[29] the average earnings of employees working overtime was 31 cents below the level of those on a 40-hour week. Overtime was highest in the two wholesale lines with the lowest average hourly earnings (groceries and farm products), and earnings were higher in average overtime hours per employee as well as per employee working overtime.

These gross observations tend to support the conclusion of T. Aldrich Finegan's careful study of factors that affect a worker's propensity to work long hours.[30] After correcting for other important variables he concluded that as wages increased, workers would use their higher earning ability to purchase more leisure. This supports the belief in a negatively sloped labor supply curve; that is, after some point is reached, fewer hours of work will be supplied at higher wage rates. Or to state it in terms of the issues under consideration in this paper, when all other things are equal, lower-paid employees will supply more hours of labor than their higher-paid coworkers. Whatever the effect of increasing the overtime penalty rate might be on the supply of labor,[31] it is apparent that curtailment of overtime will necessarily affect the earnings opportunities of large numbers of low-paid workers, particularly in the short run.

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[28] Manufacturing Industries, *A Study To Evaluate the Minimum Wage and Maximum Hours Standards of the Fair Labor Standards Act*, U.S. Department of Labor, January 1965.

[29] Wholesale Trade, *A Study To Evaluate the Minimum Wage and Maximum Hours Standards of the Fair Labor Standards Act*, U.S. Department of Labor, January 1965.

[30] Finegan, *op. cit.*

[31] See Frederick Meyers, "The Economics of Overtime," in *Hours of Work, op. cit.*

The Employment Potential of Reducing Overtime

Is there any potential for increasing employment by reducing overtime hours? We have already discussed a variety of factors that would make it extremely difficult and very costly to translate certain kinds of overtime into employment in the short run. However, given a sufficient adjustment period, there is little question that increasing the cost of overtime will induce employers to find new ways to avoid overtime penalties, and that some of these adjustments will involve substitution of employment for long workweeks. It is, therefore, appropriate to examine present overtime patterns for their employment potential. In spite of exaggerated claims which have made it possible for opponents of higher penalty rates to argue that the potential is much smaller than claimed, there appears to be a substantial amount of overtime worked that could be affected by higher penalty rates. For example, the May 1964 survey shows that almost 6½ million workers who worked over 49 hours in the survey week reported that they usually worked overtime. About one out of five, or 1.3 million workers, in this group worked in occupations or industries which provided premium pay for overtime.

Although we do not know how many in this group worked over 49 hours with any regularity, it would appear reasonable to conclude that in May 1964 over a million workers were putting in substantial amounts of overtime on a regular basis, in spite of the applicable overtime penalty rates. Whether the overtime hours by this group represent a realistic employment potential cannot be answered except in terms of particular industrial conditions. The costs of changing facilities, the feasibility of improving long-run projections of production requirements, and the alternatives available to employers are among the factors that would determine the rate of substitution of employment for overtime if the overtime penalty rate was increased. The experience in the retail trade industry is somewhat discouraging. In spite of a substantial amount of overtime in 1962, the subsequent imposition of overtime penalty rates did not create increased opportunities for regular employment.

One of the interesting findings of the May 1964 survey was that almost 77 percent of those working overtime worked on Saturday or Sunday or both. For those who worked over 47 hours a week, the fraction working on week ends was well over 80 percent. To the extent that week-end work is performed on a regular basis over a long period of time, it would be possible to translate overtime hours into increased employment through a system of rotating workweeks. Table 1 illustrates a possible adjustment pattern for a plant that employs five crews and has been working Saturday overtime on a regular basis. (The example assumes full normal production on Saturday, rather than special schedules for part of the work force.) In order to provide employment for a sixth crew to replace the overtime hours worked, the company would have to make provision for full production on each day and arrange a schedule which would provide only 5 days' work for each crew.

TABLE 1. POSSIBLE ADJUSTMENT PATTERN FOR A PLANT EMPLOYING FIVE CREWS, WORKING SATURDAY OVERTIME ON A REGULAR BASIS

SCHEDULE						
Crew	M	Tu	W	Th	F	S
1	1	1	1	1	1	
2		2	2	2	2	2
3	3		3	3	3	3
4	4	4		4	4	4
5	5	5	5		5	5
6	6	6	6	6		6

As shown in table 1, this can be done, and many industries that work 7 days a week, 3 shifts a day, use a rotating shift schedule analagous to the illustration to avoid overtime hours.

There are probably two major reasons why schedules of this kind are not used more frequently. For one thing, Saturday production may not be programed over a long enough period to make a move to such a schedule feasible. Note that a cutback in production to the equivalent of 5 crews for 5 days would force a choice between eliminating Saturday work and thus providing only 4 days work for 5 of the 6 crews, or eliminating the extra crew and shifting back to a 5-day week. The other major obstacle is probably the reluctance of employees to accept a schedule which would not give them a week-end day off on a regular basis, or which changed their workweek continuously. There have been strong pressures from labor unions for overtime rates for Saturday work, as such. There would undoubtedly be resistance to regularly scheduled work on week ends for straight time rates.

The schedule described in table 1 may not be the only way to translate overtime hours into employment, but it illustrates the complications in manpower management and industrial relations which would be caused by governmental efforts to force a change in current scheduling patterns. It does not follow that no such effort should be made, but the implications of any changes in hours legislation should be analyzed with care. Since the impact of an increased overtime penalty rate would vary substantially among industries, and the extent to which the avowed employment objective might be accomplished would differ greatly among industries, an overall increase in the overtime penalty rate would not seem appropriate. The costs in some sectors could far outweigh the possible benefits in others. Furthermore, since the employees in a given industry may have to bear a substantial part of the burden of increasing the overtime penalty rate in the form of reduced real earnings or inconvenient shifts and workweeks, there is a strong argument in favor of permitting flexible arrangements based on the preferences of the parties concerned. A decision process which considers employee attitudes toward income, work schedules, and employment, as well as employer estimates of the costs of the various alternatives, is more likely to avoid costly constraints that have no realistic potential for job creation.

Moonlighting as a Source of Employment Opportunity

Another group often looked to as a source of new jobs is the moonlighter. In May of 1964 there were 3.7 million persons, 5.2 percent of all employed persons, with two jobs or more. Over a million of these workers held one of their jobs in agriculture, and a substantial number were self-employed either in their first or second jobs. However, after subtracting these there remain almost 2 million wage and salary workers who held two jobs in nonagricultural industries. Were these moonlighters taking up jobs that could have been filled by the unemployed? In the most recent Labor Department analysis of this area,[32] Hamel and Bogan conclude that "multiple job holders generally are not depriving unemployed persons of employment opportunities. Comparatively few jobless workers could or would take the secondary jobs held by dual job holders." Their conclusion is based to a large extent on the observed mismatch between the characteristics of the unemployed and moonlighters. For example, the level of moonlighting is highest among men 35 to 44 years of age, who have the lowest rate of unemployment; whereas teenagers and older persons who had relatively high unemployment rates also had the smallest proportions with more than one job. In this instance, however, the use of rates is inappropriate, since there were still a substantial number of unemployed workers in the 35–44 age group, and there is no reason to believe that age would necessarily disqualify younger workers from filling jobs now held by older workers. Of the moonlighters, 414,000 were operators in their second category, and 248,000 were nonfarm laborers. The fact that there was a larger number of unemployed workers in each of these categories does not indicate that unemployment could not have been reduced substantially if the moonlighters had been replaced from the ranks of the unemployed.

The study by Hamel and Bogan points out that unemployed persons primarily seek full-time jobs, while the average moonlighter worked only about 13 hours at his second job. Only a small number of the unemployed would be willing to replace the moonlighters since about 85 percent of the unemployed are seeking full-time work. In addition, in May 1963, teenagers in school were about half of the unemployed looking for part-time work; 20 percent were women between the ages of 20 and 54; and workers over 55 made up another 15 percent. It is doubtful that very much from this part-time labor force would be able to replace moonlighters on their second jobs.

However, this direct comparison of the two groups understates the extent to which employment opportunities might be affected by moonlighting. The significant question is not whether the unemployed would be willing or able to fill the part-time jobs now taken by moonlighters. Rather, the issue is whether employment opportunities would be increased if the work now performed by moonlighters had to be done in some other way. If moonlighting employees were not available, employers would have to move to the next best alternative. At the present time, that might involve scheduling additional overtime, but it might also involve rearranging schedules in such a way that the work could be done by additional employees. In short, some work performed by moonlighters, particularly in the form of wage and salary employment in nonagricultural industries, represents an addition to the available supply of labor, and as such competes with the full-time labor force for the available work.

Although moonlighting may be a significant factor in some sectors of the labor force, the practice cannot be blamed for the relatively high unemployment rates we have had in the last 8 years. The number of individuals with more than one job has remained relatively stable since 1956, and the fraction of employment represented by dual job holders is about the same today as in 1957. It is probably academic to consider moonlighting jobs as a possible source of additional job opportunities. It is difficult to envisage a public policy that could be effective in reducing the practice. Unions generally take the problem seriously only when it involves workers taking secondary jobs in the same industry at substandard rates. Most dual job holders worked in a different industry at their second job, and a very large percentage moved into a different occupation[33] (80 percent for those whose primary jobs were sales workers and operators). The union position that they want workers paid enough so that a second job will be unnecessary assumes that higher wages will reduce moonlighting. But low wages do not appear to be an important cause of moonlighting, since there is little difference between the median wage and salary earnings on the primary job between dual and single job holders. Harold Wilensky has hypothesized that the typical moonlighter is a person "caught in a life-cycle squeeze . . . he has many dependents and family resources below what his modest aspirations require."[34] I would conclude that moonlighting has a very small but not insignificant effect on the labor market, but that the practice will undoubtedly continue as long as American workers increase their aspirations at least as rapidly as their earning potential.

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[32] Harvey R. Hamel and Forrest A. Bogan, "Multiple Job Holders in May 1964," *Monthly Labor Review*, March 1965.

[33] Hamel and Bogan, *op. cit.*

There has been some concern expressed that a reduction in the hours of work might lead to an increase in moonlighting which would help forestall any possible positive employment effect.

Paul Mott argues that "the trend toward the shorter workweek . . . is a major factor in accounting for the increasing prevalence of moonlighting in our society."[35] However, it appears unlikely that moonlighting would increase as a result of any reasonable reduction in the workweek. Workers with shorter hours per week (35–40) are no more likely to be moonlighters than those working 41 hours or more. In fact, the rate of moonlighting for nonfarm wage and salary workers is greater for those who work over 40 hours a week than for workers who put in 35 to 40 hours on their primary job. However, if the workweek is reduced substantially, this relationship may change. The May 1964 survey seems to show that part-time workers are more likely to be moonlighters than those who work a normal 35- to 40-hour schedule. Additional evidence that the problem cannot be ignored is the fact that moonlighting has relatively high rates for postal employees, firemen, policemen, and other government employees who may find it more convenient to arrange for a second job during their off hours. Mott also asserts that if shift work is prevalent in a community, "a worker has increased opportunity to select a second job from among the more abundant day-time jobs while he works a second or third shift at his primary job." If he is right, any increase in shift work that might result from employer attempts to avoid overtime would lead to an increase in moonlighting activity. Moonlighting should be thought of as a potential labor force adjustment process which will become more significant if the workweek and schedules change so that it can be done with less strain by more people. The moonlighting potential should be kept in mind in evaluating future policy proposals and collective bargaining trends, but it does not seem to be of major importance at the present time.

The Shorter Workweek

Another popular proposal for increasing job opportunities which has not lost its appeal is the shorter workweek. As far back as the 1880's and as recently as this year labor leaders have argued that a shorter workweek would provide more opportunities for their members. The claim has a great deal of common sense appeal, since it is apparent to all that if our present work force put in the same hours as workers did in the 1890's, our present level of demand could support only a fraction of the labor force. In spite of the obvious nature of this fallacy and of the unmistakable fact that the long-run reduction in the workweek has not reduced unemployment over the years, the belief that a shorter workweek will increase employment has not disappeared.

There is no question that work sharing can give workers more employment at lower average workweeks. Cost increases associated with scheduling problems aside for the moment, this simply means that a larger number of workers can produce a given output at approximately the same cost if they share the working hours utilized in the production process. In 1940, a BLS survey of the collective bargaining agreements it had on file showed that about one-quarter of the covered workers had work-sharing arrangements.[36]

In 1955, only a very small fraction of the contracts on file with the BLS provided for work sharing in lieu of layoffs, although about one-quarter of the agreements with layoff provisions provided also for some reduction in hours (frequently to 32 a week) which was to be enforced before layoffs began.

But work sharing at stable hourly wage rates is not the program that labor leaders have in mind when they assert they must fight for a reduced workweek in order to alleviate the unemployment problems in their industries. What they do have in mind is a reduced workweek at the same weekly pay. This is, of course, the equivalent of a substantial increase in wages, the amount depending upon the extent of the hours reduction. The efficacy of this proposal as a means of reducing unemployment has been examined many times and found wanting.[37] I will attempt only a very brief summary of the position that is shared by the vast majority of economists who have considered the question.[38] If the workweek is shortened without a reduction in the weekly wage, the unit cost of production will be increased in proportion to the rise in labor cost. The price will be forced up to reflect the higher labor cost, and the employment effects would be as follows:

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[34] Harold L. Wilensky, "The Moonlighter: A Product of Relative Deprivation," *Industrial Relations*, October 1963.

[35] Paul E. Mott, "Hours of Work and Moonlighting," in *Hours of Work, op. cit.*

[36] *Monthly Labor Review*, June 1940, pp. 13–41. The results of this survey and of subsequent studies of collective bargaining agreements, as well as an analysis of the implications of a shorter workweek, are presented by Clyde E. Dankert in hi chapter "Automation, Unemployment, and Shorter Hours," in *Hours of Work, op. cit.*

[37] Recently in "The Shorter Work Week," by Marcia L. Greenbaum, published by the New York State School of Industrial and Labor Relations at Cornell, and in *Hours of Work, op. cit.*

[38] For simplicity I will assume that overtime is not permitted and that moonlighting will not increase.

> A. If at the higher price consumers spend the same dollar amount, the number of units sold will decrease; there will be no increase in employment; and the real wages of the employees in this industry will increase only to the extent that their hourly wages increased more rapidly than the price level. If the price level increases at the same rate as their hourly wages, they will have achieved an increase in leisure at the cost of a reduction in real income, and without an increase in employment.
>
> B. If the elasticity of demand for this particular product is relatively high, there will be a reduction in the amount of dollars spent for the product; in addition to the effects described under A, employment in the industry will fall below its previous level.
>
> C. If demand for the product is relatively inelastic, the number of units sold will not decrease as much as prices increase, and there will be more jobs in the industry at the reduced workweek. However, once again this would be accomplished only by reducing the real incomes of other workers as prices increase. Just as in the case of wage increases, some groups may be able to force their hourly rates up faster than others, and the reduction in real wages may not be evenly distributed.
>
> In the absence of an increase in total demand, an increased expenditure for this product would imply a reduction in sales elsewhere in the economy and a consequent loss of jobs. An increase in total demand would be required to support an overall increase in employment at the new higher price level. Notice that even if this takes place, the original work force will still have a reduced weekly real income to balance against their increased leisure. There is no mystery here. A reduction in the workweek under modern conditions implies a reduction in output. If that reduction is made up by increasing the number of people working, the total will have to be shared by the larger work force. Consequently, unless there is a redistribution of income between wages and profits, employed workers will have to accept a reduction in real income.

The proponents of shorter hours argue that the hours reduction without a reduction in weekly pay will automatically create the demand to increase employment. Dankert summarizes the argument as follows:

> The central idea here is comparatively simple: Reduce the hours of present workers but without impairing their earnings, and turn over the hours of work thus made available to unemployed workers, enabling them to have a regular wage income. The new income of the latter group added to the preserved earnings of the former groups will result in an increased volume of purchasing power. This, in turn will stimulate the economy to higher levels of growth and to more man-hours of employment.[39]

This "raise the economy by its bootstraps" argument ignores two critical issues. First of all, even if it would work exactly as argued, the higher prices required by the increased labor costs would imply a reduced real income for the originally employed labor force. Thus, the curtain of inflation would be used to disguise an overall work-sharing policy. Of even greater importance is the shaky assumption that overall demand will automatically increase enough to purchase the total product at the higher price level. Total private demand is made up of consumption and investment. There seems a high probability that the kind of pressure on costs and profits implied by the shorter-hour proposal would reduce, rather than increase, total demand.

Legislation might force a reduction of the workweek, and collective bargaining might preserve real weekly earnings, but employers will hire additional workers only if it is profitable to do so. Real incomes are determined by production, so that in the absence of an increase in labor productivity, reduced hours of work must mean less real income for someone. This will be true whether or not demand can be increased to provide jobs for new employees. There is no apparent way that a shorter workweek can produce an overall increase in employment without some form of work and income sharing.

It is possible for a union in a very strong bargaining position in an industry with a very low, short-run demand elasticity to increase job opportunities by reducing the workweek at the same or higher weekly wages. Its power to do so would be greatest in a tight labor market. If the workweek is shortened in a period of high demand, any subsequent increase in employment may not be attributable to the shortened workweek. A case in point is the contract negotiated in 1962 by the New York City electrical industry and Local 3 of the International Brotherhood of Electrical Workers. At the time the new contract was signed there was a shortage of electricians in the New York City area.[40] Their new contract reduced the workweek by 5 hours (to 25 hours at straight time and 5 hours of overtime). After the contract was signed, Theodore W. Kheel, Director of the Office of Impartial Review of the New York City Electrical Industry, projected an increase in employment of 1,600 new jobs resulting from the contract. In a subsequent report, he estimated that between 800 to 1,000 new jobs resulted from the reduced workweek at a level of construction that was somewhat below the peak of the previous year.[41]

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[39] Dankert, in *Hours of Work, op. cit.*, p. 170.

[40] Statement of W. W. Wirtz, Secretary of Labor, for the Select Subcommittee on Labor, House Committee on Education and Labor on H.R. 9802, July 21, 1964.

[41] Remarks prepared by Theodore W. Kheel, Director of the Office of Impartial Review of the New York City Electrical Industry, for submission to the Conference on Solutions to the Problems of Automation and Employment. Hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Repr., 88th Cong., 1st Session, on H.R. 335, H.R. 3102, H.R. 3320, and H.R. 1680, part 2, p. 544.

However, as a quid pro quo for the shorter workweek, the union agreed to admit 1,000 new apprentices and to liberalize the assignment of apprentices on jobs. It seems reasonable to attribute a substantial part of the increased employment to the liberalization of the restrictions on the supply of labor in a tight labor market. There is also the longer-run question of the impact of higher costs of construction on demand for craftsmen in the New York area. Only a careful study of the New York experience could properly allocate the credit for the increased employment opportunities and assess the long run implications of the new contract. The reduced workweek was only one part of a very complex situation.

It has been argued that the increased costs associated with the reduced workweek would not materialize because labor productivity would increase as hours decline, thus preventing an increase in unit labor costs. Aside from the fact that the available evidence does not support the claim that hours reductions from the present levels would increase labor productivity enough to forestall a reduction in output and an increase in labor costs, the argument defeats its own purpose. If it were true that productivity would increase enough so that the same labor force could produce a given output in a shorter workweek, there would be no basis left for believing that a reduction in hours would increase employment. The current demand would provide for the same level of employment as before.

In short, one can say that employment can be increased if a way can be found to spread a given amount of production over a larger work force. However, in order to accomplish this, those who were employed prior to the change would, necessarily, on the average, have to accept a lower level of real income. Even work-spreading of this kind may not be successful if the process leads to a cost squeeze on employers, which in turn causes a reduction in investment spending, demand, and real output. Any increase in labor productivity associated with a reduction in hours would alleviate the cost impact, but to the same extent, would reduce the employment-creating potential of the workweek reduction. In the world of work, as elsewhere, there is no such thing as a free lunch. In order to increase job opportunities without reducing the real incomes of presently employed workers, there must be an increase in the demand for real goods and services. This is a necessary condition, whether or not the workweek is reduced, and whether or not employed workers take a fraction of their increased productivity in the form of greater leisure. While small groups of workers can increase their job opportunities at the expense of other workers and the economy in the short run, the only way a reduction in the workweek could stimulate employment overall would be through a reduction in real income of presently employed workers.

The Costs of Supply Restrictions

As indicated above, a reduction in the workweek does not appear to this author to be a likely source of substantial employment opportunities, either through a reduction in the standard workweek, the reduction in overtime through an increased penalty rate, or the discouragement of moonlighting. It might be argued, however, that even if the probability is slight, the workweek should nevertheless be shortened to take advantage of whatever possibilities exist. The reasonableness of this position depends upon the social costs that might be incurred by the proposed workweek reducing policies. The obvious and immediate effect would be a reduction in real output and economic growth. There appears to be little doubt that a reduction in hours from the present workweek would not increase productivity per man-hour sufficiently to prevent a decline in total output.[42] It could be argued that we have traditionally taken a larger fraction of increased productivity in the form of leisure than we have in recent years. A frequently quoted estimate made by Clark Kerr [43] is that between 1850 and 1920 workers took half their share of productivity improvement in the form of income and the other half in the form of leisure. Between 1920 and 1950 he estimates they took 60 percent for income and 40 percent for leisure. Peter Henle estimates that, from 1940 through 1960, only 11 percent of productivity gains were taken in the form of more leisure.[44] However, this apparent reduction in the fraction of increased productivity taken in the form of leisure is misleading. In the earlier periods there may not have been any sacrifice of income to obtain more leisure. When the workweek was very long, hours reduction frequently could be accomplished with no reduction in output. Brown reports that in about half the cases reported, decreasing hours from 52 to 48 did not decrease output,[45] a phenomenon that was probably more pronounced at longer workweeks.

What little evidence there is supports the assumption that as the workweek has become shorter each successive reduction in hours has been associated with a smaller increase in productivity. Any reduction from 40 hours would almost certainly lead to a reduction in total output, and an increase in leisure would require a sacrifice of income. But we would have to know the relationship between hours of work and productivity to calculate the income workers could have had if they had not reduced their working hours. Conclusions drawn from the ratio of hours reduction to productivity change assume that the two are independent. When the functional relationship is recognized, it is not clear what is meant by "fraction of increased productivity taken in the form of leisure." Using a more operational criterion for comparison, since 1940 workers almost certainly sacrificed a larger percent of their potential increase in real income to obtain more leisure than they had in the period before World War I.

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[42] For a complete discussion of the available evidence, see in particular David G. Brown, "Hours and Output," in *Hours of Work, op. cit.*

[43] Clark Kerr, "Discussion," *American Economic Review,* May 1956, p. 219.

[44] Peter Henle, "Recent Growth of Paid Leisure for U.S. Workers," *Monthly Labor Review,* March 1962, p. 256.

[45] Brown, in *Hours of Work, op. cit.*, p. 151.

In a period in which our world obligations are increasing, and when we are attempting to carry out an effective war against domestic poverty and using a substantial fraction of our resources for defense and space purposes, we should hesitate to take any public action that would result in a reduction in our productive potential through limiting the supply of labor. It is one thing for the workweek to be reduced gradually over time as the labor force expresses its preference for leisure over income. It is quite another thing to use the force of public policy to accelerate this change. It would be difficult to demonstrate that the current balance between leisure and income is optimum in any sense. Indeed, it may be true, as Denison suggests, that "unless employers and employees know that amount by which production is impaired by shorter hours, rational decisions are impossible. I do not believe either employers or employees have this information. Nor, with the present great uniformity of standard hours, can it be supposed that competition among firms, leading to expansion of those arriving at the correct level of hours and contraction of those that do not, serves as a substitute mechanism to assure arrival at a correct level."[46] However, there is little evidence that workers would prefer shorter hours at present wage levels. A few years ago, George Brooks noted the absence of evidence that workers want shorter daily or weekly hours. He agreed that "The evidence is all on the other side. Hundreds of local and international officials have testified that the most numerous and persistent grievances are disputes over the sharing of overtime work. . . . Workers are eager to increase their income, not to work fewer hours."[47]

Indeed, the pressure for higher overtime penalties and a shorter workweek is apparently unrelated to the possible preference for increased leisure. These policies would tend to force a change in the current balance between work and leisure to increase employment opportunities.

In his excellent article "Hours of Work and the General Welfare," in the Industrial Relations Research Association volume, *Hours of Work*, Melvin Reder discusses several other factors which should be considered in evaluating policies that would increase the overtime penalty rate or reduce the number of hours after which penalties became applicable. He points out that output and employment would expand in an industry or sector in which unit costs decreased relative to other industries or sectors. Overtime penalty rates would increase marginal costs and restrict the use of overtime that might be necessary as the more efficient sector expanded. As a result, output would be diverted from low-cost to higher cost firms and the economy would pay a price in loss of efficiency. This loss should be weighed against the possible social gain of the overtime penalty rate.

Reder also points out that overtime penalty rates increase the trade-off between unemployment and inflation as the economy moves towards capacity gross national product. The greater the overtime penalty rate the more rapid will be the rate of price increases and the reduction in straight time real wages, as the expanding economy approaches capacity and uses more overtime. For those interested in reducing unemployment, this has serious implications. An important limit on the use of expansionary monetary and fiscal policy is the risk of inflation. A shorter workweek or an increase in the overtime penalty rate would cause the inflation danger signals to be raised at lower levels of gross national product and would make it more difficult to lower the unemployment rate.

Conclusion

In summary, I share the goal of increasing employment, which is the avowed objective of proponents of shorter workweeks and higher overtime penalty rates. However, I view the employment-creating potential of such policies as extremely limited, and have tried to suggest that they are far from costless. Furthermore, there are more effective policies available for increasing employment in our economy. It has been the failure of the Government to make effective use of these policies in recent years which has caused the labor movement and its supporters to turn in frustration to other measures. This may be far from irrational on their part. As indicated above, at least in the short run, it may be possible for strongly organized groups to increase employment opportunities for their members at the expense of the rest of the economy. A fuller recognition of the limitations of hours reduction might serve to strengthen the general support for employment-expanding monetary, fiscal, and manpower policies, and to strengthen the resistance to work-sharing pressures that would limit their effectiveness.

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[46] Edward F. Denison, *The Sources of Economic Growth in he United States and the Alternatives Before Us*, New York, Committee for Economic Development, 1962, pp. 36–40.

[47] George Brooks, "History of Union Efforts to Reduce Working Hours," *The Shorter Work Week*, Public Affairs Press, Washing-on, D.C., 1957.

THE LEISURE COMPONENT OF ECONOMIC GROWTH

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The Leisure Component of Economic Growth

I. Introduction*

> Mr. Creech, it is said, wrote on the margin of the *Lucretius* which he was translating, "Mem.—When I have finished my book, I must kill myself." And he carried out his resolution. Life . . . is a dreary vista of monotonous toil, at the end of which there is nothing but death, natural if it so happen, but if not, voluntary, without even a preliminary interval of idleness. To live without work is not supposed to enter into our conceptions.[1]
>
> The contemporary intellectual revolution, generally referred to by the technical word, automation, is providing machines which . . . assuming drudgery and monotonous repetitive operations, increase productivity. Within the industrial system a relentless logic necessitates abundance. Leisure, as we experience it, becomes a function of an unseen but very real and enormously fruitful configuration of scientific concepts and theories. . . .[2]

Transition from the first of these two views—that the purpose of life being work, life itself might well end when work ends—to the second—that life is greatly enriched by a technology which reduces the amount of work necessary—has not been an orderly one, and even today there is no unanimity of opinion as to the value of leisure.

Twentieth century views of leisure are often difficult to fathom. In contrast to Aristotle's belief that "the goal of war is peace, of business, leisure," the uneasy feeling that life with little work has little purpose seems to pervade much of today's thought. Contemporary writers often deplore the growing freedom from work, which provides "a great emptiness," devoid of meaning. Lacking training for leisure and having no strong interests or devotions, one author argues, persons without work lead dismal lives. The void created by leisure has thus replaced ". . . the days when unremitting toil was the lot of all but the very few and leisure was still a hopeless yearning."[3] In less extreme form, concern is frequently voiced over the idleness forced upon youth because of lack of job opportunities, and the elderly because of early and compulsory retirement from work.

Americans have traditionally believed, according to Margaret Mead, that leisure should be earned before it is enjoyed. The function of recreation is to prepare man for further work, and as soon as it appears that there will be more time available than is actually needed for this purpose.

> . . . Alarm spreads over the country. People are going to have too much leisure. . . . This means more time than is needed to relax and get back to work again—unearned time, loose time, time which, without the holding effects of fatigue before and fatigue to come, might result in almost anything.[4]

Unfortunately, experience has indicated that changes in the relationship between time at work and time free for leisure have often resulted in boredom and apathy, or excessive and frantic activity. But the philosophy that leisure must be earned and reearned has changed since World War II, the author continues. It is the home and family that now stand center stage, and the job is subsidiary to the good life. Men value jobs that allow them a maximum of time at home and a minimum of strain and overwork on the job. "As once it was wrong to play so hard that it might affect one's work, now it is wrong to work so hard that it may affect family life."[5]

Extent of any change in attitude toward leisure is of course difficult to estimate, although there is ample evidence, both in the pressure for a statutory reduction in the workweek and in union negotiations for reduced hours per week, longer vacations, earlier retirement, etc., that increased free time is being actively pursued. The critical question of whether this pursuit reflects a genuine desire for free time, or whether it is primarily an attempt to increase the number of jobs, appears not to be at issue currently. Instead, labor leaders usually argue that as long as there is unemployment the workweek is too long, and

> . . . Aside from the workers' desire for their paid holidays and paid vacations, there is no evidence that workers want shorter daily or weekly hours. The evidence is all on the other side. Hundreds

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[*] The authors wish to acknowledge the assistance of Mr. Donald E. Pursell and Mr. Louis Pisciottoli in the preparation of the manuscript.

[1] Leslie Stephen, "Vacations," reprinted from *Cornhill Magazine*, vol. 20 (1869), in Eric A. Larrabee and Rolf Meyersohn, *Mass Leisure* (Glencoe, 1958), pp. 281–290.

[2] Paul F. Douglass, foreword to "Recreation in the Age of Automation," *Annals of the American Academy of Political and Social Science*, vol. 313 (September 1957), p. ix.

[3] Robert M. MacIver, *The Pursuit of Happiness* (New York, 1955). Chapter 6 is reprinted in Larrabee and Meyersohn, *op. cit.*, pp. 118–122.

[4] Margaret Mead, "The Pattern of Leisure in Contemporary American Culture," *The Annals of the American Academy of Political and Social Science*, vol. 313 (1957), p. 13.

[5] *Ibid.*, p. 14.

> of local and international officials have testified that the most numerous and persistent grievances are disputes over the sharing of overtime work. The issue is not that he has been made to work, but that he has been deprived of a chance to make overtime pay. Workers are eager to increase their income, not to work fewer hours.[6]

The question of whether increases in nonworking time are chosen in preference to increased incomes or whether leisure will grow only as a result of efforts to spread the work may turn, in part, on the form of the potential leisure. A reduction in the workweek, for example, may have much less utility to the worker than an increase in vacation time. Leisure in the form of early retirement may have the lowest utility of any form of free time (save unemployment). If free time is to grow as technology improves—if in fact leisure is to be as characteristic of our times and ". . . as representative of our modern spirit as the Parthenon was an expression of the age of Athens"[7]—the form in which this leisure emerges is of some significance. Not only does the temporal distribution of leisure affect its value; the distribution of income through the life cycle is also influenced by the apportionment of working and nonworking time.

In the ensuing discussion, the issues indicated above are analyzed. Specifically, the question of workers' pursuit of income as opposed to leisure is treated, with reference particularly to their concealed (as compared with revealed) preference. The distribution of leisure and earned income through the lifespan and the economic implications of different distributive arrangements are then discussed. Throughout these two major phases of the analysis, certain central questions reappear in different contexts: One, what are the present dimensions of leisure, both for the individual worker and for the economy, and to what extent will future growth confer further increases in leisure? Two, when is free time preferred to income, and vice versa? Three, what are the preferred forms and temporal distributions of leisure? Finally, what institutional arrangements will be necessary to accommodate the increases in total leisure made possible by economic growth, and to facilitate the preferred distribution of this leisure through the lifespan?

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[6] George Brooks, "History of Union Efforts To Reduce Working Hours," *Monthly Labor Review*, vol. 79 (November 1956), p. 1273.

[7] Paul F. Douglass, *op. cit.*, p. ix.

II. Growth and Dimensions of Leisure

Today's worker receives the equivalent of a 4-month holiday, paid, each year. If he followed his grandfather's schedule of hours per week, he could work from October through May, then vacation till October. Or if he preferred, he could work April through November, and ski all winter.

He takes his nonworking time in different forms, but in total he enjoys about 1,200 hours per year more free time than did the worker of 1890. Moreover, he enjoys more years in which he doesn't work at all; he enters the labor force much later in life, and has several more years in retirement than his grandfather. In total, this increase at the beginning and the end of worklife has given him about 9 additional nonworking years. Yet lest the worker of today be labeled a loafer, it should be noted that since he lives longer, he works more hours in his lifetime than his predecessor; if born in 1960 he will probably log about 6,800 more hours than the male born in 1900.

A. The Forms of Leisure[1]

On the average, the employed person worked 40.7 hours a week in 1963; in 1890, the average was 61.9. Paid holidays have increased by at least 4 per year during this period, to about 6 at present, and paid vacations averaging 1½ weeks per year have added at least 6 days free time annually. Sick leave amounts to the equivalent of 1 week, giving the following increases in nonworking hours per year between 1890 and the present:

Source	*Approximate hours*
Reduction in workweek (21.2 per week)	1,100
Increase in paid holidays (4 days)	32
Increase in paid vacations (6 days)	48
Increase in paid sick leave (1 week)	40
Total increase	1,220

Thus, the shortened workweek has accounted for most of the century's rise in free time during worklife. The addition of 9 years of nonworking time raises the male's number of years outside the labor force by about 50 percent. If, instead of spending this free time in gaining additional education and in retirement, man worked on the average 2,000 hours per year during these years, he would work during his lifetime an additional 18,000 hours, or 435 hours per year (with a worklife expectancy of 41.4 years). Thus the amount of nonworking time bunched at the beginning and end of worklife has grown by about one-third the amount added annually through workweek reductions, added vacations, etc.

The definitions of leisure are many. At one extreme, the term is used to denote all nonworking time; at the other, it applies quite restrictively to that time which is completely free of commitments—contemplative time, in short. The concept of leisure as "discretionary" time has also been developed, and for many purposes this is the most meaningful use of the word leisure. However, the major purpose of this portion of the study is to indicate the dimensions of present and future time free of work done for pay; for the moment, this nonworking time is referred to arbitrarily as leisure. A case can easily be made for the fact that increasingly such nonworking time is absorbed in activities associated either with the work itself (as in the case of commuting time) or with the growing complexities of modern life. De Grazia has dealt in detail with the difference between nonworking time and leisure. In subsequent sections of the analysis, in which the terms leisure and nonworking time are not used synonymously, the distinction is explicitly made.

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[1] For historical data on hours of work, vacation time, paid holidays, sick leave, etc., see *Hours of Work*, Hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Representatives, 88th Congress, 1963, parts I and II, particularly the summary data presented by Ewan Clague, pp. 73–104 of part I. See also, J. Frederick Dewhurst and Associates, *America's Needs and Resources* (New York, 1955), and various *Monthly Labor Review* articles, including: Arnold Strasser, "Plant and Paid Leave Hours in Manufacturing, 1959 and 1962," vol. 88 (April 1965), pp. 413–415; Frances Jones and Dorothy Smith, "Extent of Vacations With Pay in Industry, 1937," vol. 47 (July 1938), pp. 269–274; unsigned, "Vavations with Pay in Union Agreements, 1940," vol. 51 (November 1940), pp. 1070–1077. See also, "Paid Sick Leave Provisions in Major Union Contracts," 1959, Bureau of Labor Statistics, *Bull. No. 1282* (November 1960); Enzo Puglisi, "Employer Expenditures for Selected Supplementary Remuneration Practices for Production Workers in Manufacturing Industries, 1959," Bureau of Labor Statistics *Bull. No. 1308* (January 1962); and Seymour Wolfbein, "Changing Patterns of Working Life," U.S. Department of Labor, Manpower Administration (August 1963). Several articles by Peter Henle deal with the overall growth in leisure; see his "Recent Growth of Paid Leisure for U.S. Workers," *Monthly Labor Review*, vol. 85 (March 1962), and "The Quiet Revolution in Leisure Time," *Occupational Outlook Quarterly*, vol. 9 (May 1965), pp. 5–9. An earlier summary by Joseph Zeisel, "Labor Force and Employment in 1959" appeared in *Monthly Labor Review*, vol. 83 (May 1960). Finally, see Clyde E. Dankert and Associates, *Hours of Work* (New York 1965), which is a series of analytical articles by Herbert R. Northrup, Richard L. Rowan, Ray Marshall, W. R. Dymond and George Saunders, Paul E. Mott, Frederic Meyers, Floyd C. Mann, Dean F. Berry, David G. Brown, Clyde E. Dankert, and Melvin W. Reder.

1. *Hours of Work Per Week*

Average weekly hours have declined by one-third since 1890, as table 1 and figure 1 indicate. The sharpest drop occurred between 1900 and 1920, when average hours fell from 60.2 to 49.7, or one-half hour per year. During the next two decades the decline was only 5.4 hours, and at the end of World War II the average again hit the 1940 figure of 44 hours. Since 1946, weekly hours have fallen very slowly—slightly more than three—although significant increases in free time have emerged in other forms.

The recent relative stability of working hours per week, in contrast to the rapid growth in free time in the form of vacations, early retirement, etc., would seem to indicate that the preferred form of leisure has shifted since early in the century. And although the drive for a shorter workweek continues, the primary purpose of proposed reductions is an expansion in the number of jobs, and to date attempts to amend the Fair Labor Standards Act by establishing a shorter maximum workweek have been resisted. For the most part, predictions of future workweek changes indicate only small declines in the next decade or so. Peter Henle suggests a limited weekly reduction of 1 or 2 hours between now and 1980,[2] while the National Planning Association projects an average workweek of 36 hours by that year.[3]

2. *Paid Vacation Time*

Whereas the major gains in workweek reductions occurred early in the century, growth in leisure via paid vacations (particularly for wage earners) has been largely a postwar development. In 1900, perhaps one-third of the salaried employees received paid vacations but only about 2 percent of the wage earners in manufacturing. By 1929, a majority of salaried employees, but only slightly more than one-fourth of the wage earners in manufacturing, had paid vacations.[4]

In 1940, paid vacations for wage earners were still the exception rather than the rule, with 1 week usually being the maximum length.[5] A study of union members in 1940 indicated that 2 million, or approximately one-fourth of all organized wage earners in the United States, were under collective bargaining agreements providing annual vacations. Most of the men covered were eligible for only 1 week, although a fourth of the

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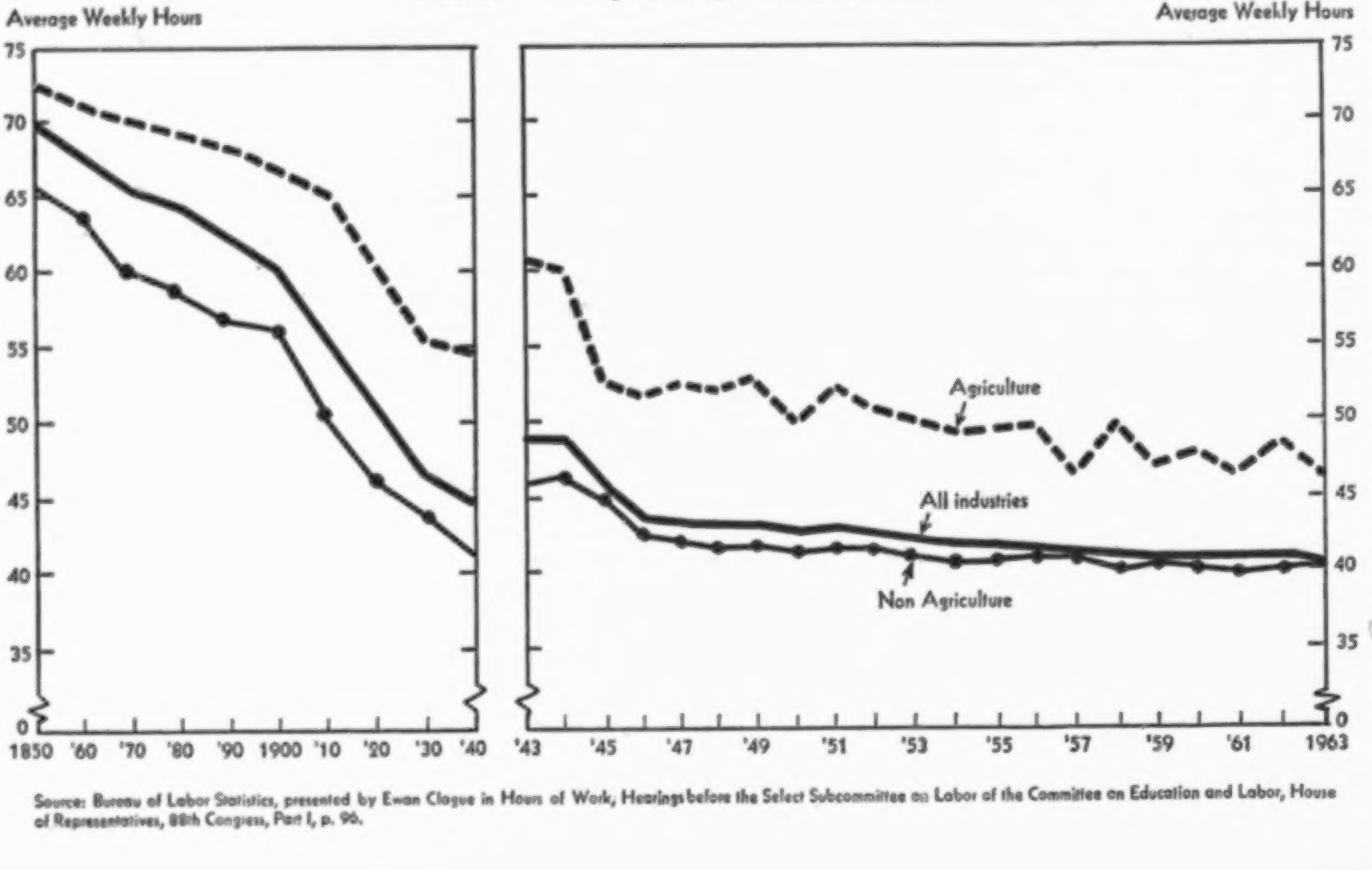
[2] Peter Henle, "The Quiet Revolution and Leisure Time," *op. cit.*, p. 9.

[3] National Planning Association, preliminary estimates provided by Joel Darmstadter.

[4] Frances Jones and Dorothy Smith, *op. cit.*

[5] Dema Wolk and James Nix, "Paid Vacation Provisions in Collective Agreements, 1952," *Monthly Labor Review*, vol. 75 (August 1952), pp. 162–167.

FIGURE 1. *Average Weekly Hours From 1850*



Source: Bureau of Labor Statistics, presented by Ewan Clague in Hours of Work, Hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Representatives, 88th Congress, Part I, p. 96.

TABLE 1. AVERAGE WEEKLY HOURS, 1850 TO 1963

Year	All industries	Agriculture	Nonagricultural industries
1963	40. 7	46. 9	40. 2
1962	40. 9	48. 7	40. 2
1961	40. 4	46. 3	39. 9
1960	40. 8	48. 0	40. 1
1959	41. 1	47. 9	40. 4
1958	41. 0	49. 6	40. 0
1957	41. 1	46. 3	40. 5
1956	41. 6	49. 6	40. 7
1955	41. 9	49. 5	40. 9
1954	41. 6	49. 3	40. 6
1953	42. 1	50. 0	41. 2
1952	42. 6	50. 9	41. 5
1951	43. 2	52. 6	41. 9
1950	42. 5	50. 1	41. 3
1949	43. 5	53. 3	41. 7
1948	43. 4	52. 5	41. 9
1947	43. 8	52. 9	42. 2
1946	44. 0	51. 5	42. 6
1945	46. 3	52. 4	45. 1
1944	49. 3	60. 2	46. 9
1943	49. 1	61. 3	46. 4
1940	44. 0	54. 6	41. 1
1930	45. 9	55. 0	43. 2
1920	49. 7	60. 0	45. 5
1910	55. 1	65. 0	50. 3
1900	60. 2	67. 0	55. 9
1890	61. 9	68. 0	57. 1
1880	64. 0	69. 0	58. 8
1870	65. 4	70. 0	60. 0
1860	68. 0	71. 0	63. 3
1850	69. 8	72. 0	65. 7

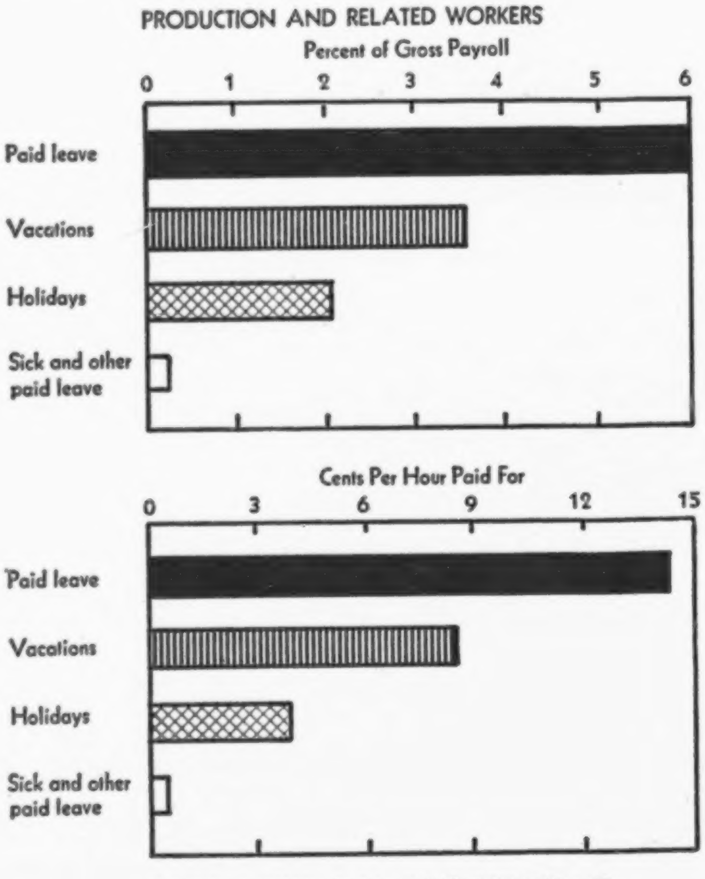
NOTE: Data from 1943–63 relate to actual hours of work during the survey week by members of the labor force who were at work. Data are for the month of May of each year and reflect hours worked at all jobs during the week. These figures are based on interviews obtained in the monthly survey of households.

SOURCE: 1850–1940, Dewhurst & Associates, *America's Needs and Resources*, 1955. 1943–63, U.S. Bureau of the Census and U.S. Bureau of Labor Statistics, as presented by Ewan Clague in "Hours of Work," hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Representatives, 88th Congress, part I, p. 76.

agreements allowed a maximum of 2 weeks.[6] By 1961, virtually all collective bargaining contracts of any size had paid vacation provisions covering almost all of their employees.[7] In major collective bargaining agreements, 91 percent of the workers in manufacturing and nonmanufacturing industries (and 99.2 percent of those in manufacturing) received paid vacations.[8]

The maximum allowable length of these vacations has grown, along with the growth in numbers of workers covered. Eight percent of the major collective bargaining agreements in 1961 provided a maximum of 2½ weeks; 49 percent allowed 3 or 3½ weeks; and 43 percent allowed 4 weeks or more. However, long service—frequently 20 years for 4 weeks—is required for the maximum vacation; the average is much less. Henle estimates a total of 96 to 100 million weeks of vacation, or 1.5 weeks per worker. Employer expenditures on paid leave in manufacturing industries in 1962 are shown in figure 2.

FIGURE 2. *Employer Expenditures for Paid Leave, Manufacturing Industries, 1962*



Source: Bureau of Labor Statistics, Bull. No. 1428, 1965, p. 12.

In contrast to the widespread resistance to a reduced workweek, a gradual increase in vacation time is generally expected. Again, this shift from increased leisure per workweek to increased leisure in an annual lump sum would seem to reflect the preference of workers for the latter form of free time. Vacation time may, in fact, be the most desirable form of leisure for today's worker, and its growth is likely to result from voluntary agreements rather than statutory provision. Additional time for vacations is not dissipated in time spent commuting to and from a shortened workday, and its occurrence does not disturb the even flow of earned income, as does early retirement. There may be some further advantage in a possibly increased consumption of goods and services when leisure is taken in this form.

Until recently, proposals for increased vacation time have not been justified on the basis of the need to increase employment. The "sabbatical" plan negotiated by the United Steelworkers was, however, an attempt to spread work. Although the evidence is not complete, it is apparent that the increase in employment was far short of what had been hoped for, pointing up once again the difficulty of easing unemployment by reducing working time. But despite the failure of growth in vacation time to create jobs, it seems likely that this will be one of the major sources of free time in the future if workers' preferences as to the form of leisure prevail.

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[6] "Vacations With Pay in Union Agreements, 1940," *op. cit.*, pp. 1070–1077.

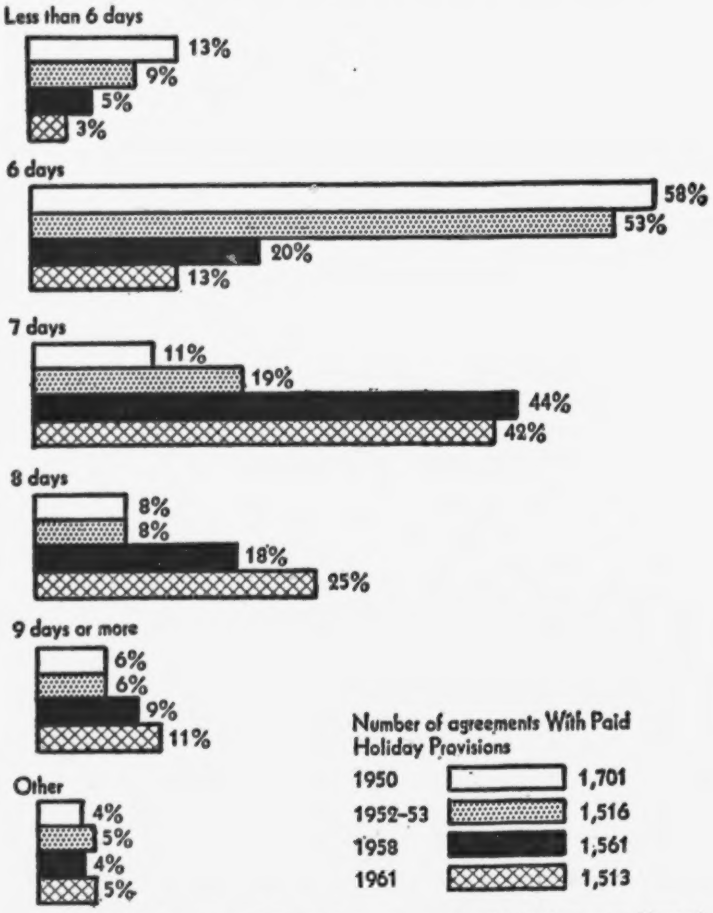
[7] Peter Henle, "Recent Growth of Paid Leisure for U.S. Workers," *op. cit.*, p. 255.

[8] Ewan Clague in *Hours of Work* Hearings, *op. cit.*, part I, p. 90.

3. *Paid Holidays*

Holidays with pay have also been a significant component of the growth of paid leisure during the postwar period. For although the custom of taking holidays is of long standing, paid holidays for wage earners in the country are for the most part a phenomenon of the past two decades. (See fig. 3.)

FIGURE 3. *Total Paid Holidays in Major Collective Bargaining Agreements, 1950, 1952–63, 1958, and 1962*



Source: BLS Study of Major Collective Agreements, presented by Ewan Clague in Hours of Work, Hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Representatives, 88th Congress, Part I, p. 104.

In 1940, it is estimated that the average worker had 2 paid holidays per year, as compared with a current average of 7 for plant workers and 7.8 for office workers in metropolitan areas. An average of 6 days per year for all workers (including farmers) thus emerges,[9] although by one method of computation the figure is slightly higher.[10] In the earlier estimate of leisure growth in all forms, 2 paid holidays for the beginning of the period (1890) was assumed; no estimates are available for years prior to 1940. Clearly, however, this understates their growth.

In speculating on the future increase in paid holidays, the immediate difficulty lies in thinking of a significant number of established holidays which are not now compensated for. However, it seems likely that one source of growth in nonworking time will be an occasional Friday off, whether or not it is in connection with an established holiday. If, in addition to the average of 6 paid holidays, workers had one 3-day weekend in each of 6 months—thereby doubling the amount of holiday time—the utility of the extra days would probably be quite high. Alternatively, these holidays would provide more than another week of vacation per year.

4. *Sick Leave and Other Compensated Nonworking Time*

Additional sources of nonworking time are paid sick leave and paid leave for miscellaneous causes (jury duty, military service, etc.), and paid clean-up and rest time. An estimate of total nonworking hours in manufacturing indicated that paid leave hours constituted 5.9 percent of the total hours paid for in 1959 and again in 1962. These paid leave hours were as follows in the latter year: 3.5 percent for vacations, 2.1 percent for sick leave, 0.2 percent for holidays (table 2). On the basis of a 50-week year, sick leave, thus accounted for 1 week of paid leave.

TABLE 2. PLANT HOURS AND PAID LEAVE HOURS AS A PERCENT OF TOTAL HOURS PAID FOR (1959 AND 1962)

Plant hours (percent)	Paid leave hours				
	Total	Vacations	Sick leave	Holidays	Other
1959 (94.1)---	5. 9	3. 4	2. 2	0. 2	(Less than 0.05)
1962 (94.1)---	5. 9	3. 5	2. 1	0. 2	

SOURCE: Arnold Strasser, "Plant and Paid Leave Hours in Manufacturing, 1959 and 1962," *Monthly Labor Review*, vol. 88 (April 1965), pp. 413–415.

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[9] Peter Henle, "Recent Growth of Paid Leisure for U.S. Workers," *op. cit.*, p. 256.

[10] From data on 1,698 major collective bargaining agreements covering 7.4 million workers in manufacturing and nonmanufacturing (see James A. Socknat, "Holiday Provisions in Major Union Contracts, 1961," *Monthly Labor Review*, vol. 85 [May 1962], pp. 522–527), an average of 6.2 paid holidays is derived. In this estimate, a "man-holidays" figure, divided by the number of workers *with* paid holidays gives 7.2 days per covered worker, as compared with 7 days for plant workers in metropolitan areas. Dividing man-holidays by the total number of workers, an average of 6.2 days (as compared with the cited figure of 6 days) per worker is obtained.

Paid sick leave provisions have not changed significantly since 1959, when a Bureau of Labor Statistics study indicated that establishments employing 22.6 percent of the production workers in manufacturing had sick leave expenditures,[11] and another survey found that about one-fifth of workers in major union agreements were covered by such provisions.[12] Increases in nonworking time from this source are difficult to estimate from these data, since the terms of the plans differ. *Uniform* plans provide a certain number of days per year, whereas *graduated* plans vary in the number of days allowed, in the provision as to full or half pay, in the number of years of work required for eligibility, etc. Of the 277 plans analyzed by the Bureau of Labor Statistics in 1959, 1 year or more of service was required for eligibility in 3 out of 5 plans.[13]

Paid rest periods are not included in the summary figures on the growth of leisure because there is very little information available on the number of workers for whom such periods are customary, the length of the rest times, etc. A 1961 study of major union agreements showed that 433 out of 1,687 contracts had paid rest period provisions; that 1.7 million out of 7.5 million workers were covered by contracts containing these provisions, but not all of the workers under these contracts were eligible for this benefit. Although the length of the rest period varied, 70 percent of the covered workers (16 percent of all workers in the study) had rest periods of 20 to 30 minutes.

The generalization that about one-fourth of the plants or one-fourth of the workers have paid rest periods does not follow, since the study dealt only with major union agreements. In practice, plant rules and custom are likely to regulate rest periods, whether or not there is a contractual agreement. The same problem of measurement exists with respect to paid cleanup time; plant rules may allow it without an explicit provision. According to a 1961 count, 17 percent of the contracts studied had cleanup provisions in 1953 and in 1959.[14]

B. Labor Force Size and Composition

Through time, the amount of leisure available in a society may increase either through a reduction in the annual hours spent on the job during working life or as a result of a decrease in the length of worklife as a proportion of total life. Men now enter the labor force later in life and retire earlier than at the end of the 19th century, thereby gaining several years of nonworking time. During the same period, however, increasing numbers of women have taken jobs outside their homes; the proportion of the adult population in the labor force has therefore remained relatively stable. On balance, then, leisure would seem not to have grown significantly as a result of this century's changes in the pattern of worklife.

Reduced hours of work rather than reduced labor force participation have accounted for the growth in leisure in other economies, as well as the United States. The explanation for this trend, according to Long,[15] lies partly in the fact that reduced hours offered a convenient and flexible means of distributing the growth in free time that accompanied rising incomes. Since a household typically has only one worker, discontinuance of the services of this worker means complete cessation of income and an uneven distribution of leisure. Shortening the workweek, by contrast, not only results in a more evenly distributed leisure for the worker; it also permits all members of the family to share this leisure. For despite the fact that the changing sex composition of the labor force would appear to be shifting from men to women, the effect of better household appliances, smaller families, and the sharing of household tasks is to apportion the increased leisure to both sexes.

1. *Labor Force Participation Rates*

The male's earlier retirement and postponed entry into the labor force have resulted in some decline in the labor force participation rate for men. From an 1890 rate of 78.1 percent, the proportion rose (though not steadily) to 89.8 in 1944, but has fallen gradually during the past two decades to 78.8. The last half a century has thus seen a decline of 9.5 percentage points, or about 11 percent in the proportion of men at work or looking for work. For women, the reverse trend has occurred: The 1890 figure of 16.2 percent had risen to 25.2 by 1910, thence to 36.8 percent in World War II. Although women's participation in the labor force declined after the war, it has subsequently increased to 37 percent and is expected to be 38.2 percent in 1975. The combined effect of these two diverse movements was to raise the overall participation rate from 49.2 percent in 1890 to 57.9 percent in 1910, then to a high of 63.1 in 1944. Since the war period, the rate has ranged only between a low of 57.2 (1946) and a high of 59.3 (1956), the 1963 figure of 57.3 being very close to that set a half-century ago (fig. 4).

Since the participation rate indicates the proportion of adults (age 14 and over) who are active in the labor force, it might be considered one measure of the extent of leisure. But the conclusion that a rising rate for women indicates a decline in their leisure would seem unwarranted; instead,

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[11] Enzo Puglisi, *op. cit.*, p. 15.

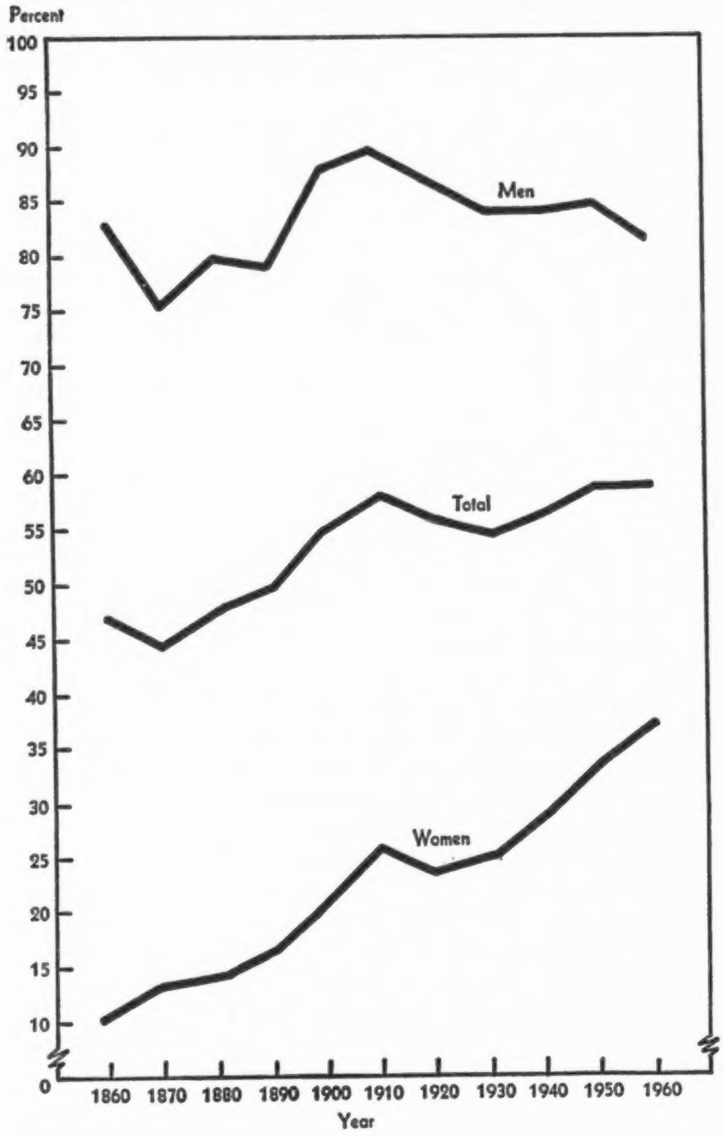
[12] Bureau of Labor Statistics *Bulletin No. 1282, op. cit.*, p. 2.

[13] *Ibid.*, p. 4.

[14] "Rest Periods, Washup, Work Clothing, and Military Leave Provisions in Major Union Contracts," Bureau of Labor Statistics, *Bull. No. 1279* (April 1961), p. 9.

[15] Clarence D. Long, *"The Labor Force Under Changing Income and Employment"* (Princeton, 1958), pp. 24–25.

FIGURE 4. *Labor Force Participation Rates, 1860–1960*



there may have been merely a change in the type of work done. In taking account of this growing labor force activity of married women, particularly, it is important to set aside the definition of leisure as time not spent on a paid job, and to consider what changes are occurring in the overall patterns of women's work both in and out of the labor force. The woman who lived and worked on a farm probably toiled much longer hours than today's salesgirl, but since only the latter is counted as a member of the labor force, attempts to measure the growth of leisure for women in the same way as for men could lead to some strange results. It is in fact very difficult to estimate the amount of actual leisure accruing to women now in comparison with any previous period for several reasons, perhaps the most important being that the role generally considered primary for the woman—running the home and rearing children—is one for which no satisfactory measures of working time and free time have been devised.

It can be argued (and information could be acquired to test the thesis) that the same advances in technology that have reduced working time in the factory have served to do so in the home as well, and that women not in the labor force have enjoyed a growth in leisure at least commensurate with that conferred on labor force participants, male and female. Evidence would seem to point to greater leisure for women who do not have jobs outside the home. Increased activity in community and social affairs, more time for literary and artistic pursuits, etc., are obvious. And although it is surely true that the free time in evidence is attributable in large measure to decreased family size (rather than more efficient household appliances), increased free time does, all the same, apparently accrue to women outside the labor force.[16]

Growth in the leisure of single women who are in the labor force is measured along with that of male workers; for the most part, workweek, vacation provisions, and retirement arrangements are the same for men and women of equal length of service and level of job. Similarly, the woman with a family who works outside the home enjoys whatever gains in free time are made generally available to workers. The question of society's net gain in free time must, however, take into account the increase in working time arising from the greater labor force participation of women with families, since these women (or their husbands) either now do the household work they formerly did, as well as the new job, or they hire someone else to do it. In the latter case, the female labor force participation rate will reflect the trade-off, and the accounts will show an increased labor force size, more hours worked, higher GNP, etc., and (if hours of work are declining) a growth in free time. But in the former instance, an actual decline in free time may be taking place. De Grazia's argument that leisure for men is diminished by the jobs their wives take and hence leisure time is not growing as rapidly as is commonly thought is a compelling one.

The fact that household services performed by members of the family do not carry price tags makes it difficult to estimate the net addition women with family responsibilities make to the total value of goods and services when they enter the work force. If domestic services were so priced, it might be discovered that many women are earning in the marketplace less than the value of their services at home, and hence the GNP is actually lowered by their labor force participation, to the extent that their household chores are left undone. Although it is true that the family sets a lower value on the household services and the leisure foregone than on the earnings realized from the sale of the woman's services in the marketplace—otherwise the outside job would not be taken—the woman's entrance to the labor force inevitably involves some substitution of work for leisure.

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[16] Note, however, Nels Anderson's comment that "a woman who does not work for hire, who is occupied with being a wife and mother. is most disadvantaged as far as leisure is concerned." See his *Work and Leisure* (London, 1961), p. 128. Anderson's position is well taken if one is concerned primarily with that period of woman's life in which she is caring for small children—"the vacationless existence" of such housewives, as he terms it.

In their analysis of income and welfare in the United States, James Morgan and his associates emphasize the importance of including the amount of leisure, along with money income, in appraising the family's welfare. Their estimates of the total amount of time required for housekeeping and child care range from 500 hours a year for a single person with no children to 2,000 hours a year for a married couple with preschool children. Adding these estimates to the time spent earning money, producing food, and making home repairs, the authors conclude that some families achieve high levels of welfare in terms of real income relative to need by spending more time in productive pursuits, whereas others who have low real incomes actually work less than average. The positive relationship between the family's material welfare level and the number of hours of leisure foregone points up the need to distinguish between the effect of rewards on working time and the larger relationship between working time (in and out of the labor force) and levels of welfare. Those people who have more income relative to their needs are the ones who spend more time working; or put differently, those with more income as goods and services have less income in the form of nonworking time.[17]

This inverse relation between income as goods and services and income as leisure suggests to the authors that using gross disposable income as a measure of welfare has the effect of exaggerating the degree of true inequality. If persons with higher goods-services income had more leisure, the effect would be the opposite one of understating the inequality of satisfaction. One might compare the influence of the relatively smaller leisure component to that exerted by a progressive tax on income, perhaps. If on a Lorenz curve the line of actual distribution of gross disposable income indicated the extent of inequality of distribution in goods and services, a second line (lying closer to the line of equal distribution) might then indicate the distribution of total satisfaction, including leisure time.

Attempts to estimate the amount of any loss in the family's leisure attributable to the increased labor force participation of wives and mothers are beyond the scope of this study. Without invoking any tools of measurement, however, it should nevertheless be remembered that the combined labor force participation rate for men and women is approximately the same now as in 1910, with the entrance of women roughly offsetting the exit of men; that increased efficiency of household appliances has been paralleled by a growth in the complex and time-consuming activities of urban living; that smaller family size can easily be counterbalanced by higher family aspirations, and so on. In the absence of such caveats, it is difficult to understand the apparent absence of leisure in the modern household. Labor force participation of married women, analyzed in detail by Jacob Mincer and Clarence Long, is discussed further in a subsequent section of this paper.

Whether the proportion of women in the labor force will continue to grow will depend to a large extent on the availability of jobs and on the possibilities for part-time work, as well as on family size. Women are often the strongest advocates of reduced working time, and their participation will lend support to the move for a shorter workweek. Long has observed that growth in the proportion of women in the labor force has been abetted by the reduction in the workweek.

> Any attempt . . . to account for the large-scale transformation from housewife or mother's helper to secretary or grinding machine operator must consider whether the shorter workweek may have been a factor in allowing a female who has typed until 5 o'clock the necessary time in which to look for a cheap roast or a rich husband.[18]

By the same token, pressure from students who prefer part-time jobs and from older persons who are being squeezed out of the labor market may be conducive to the adoption of new working arrangements. One of the methods of spreading leisure may therefore be a growth of part-time jobs, or full-time jobs for a part of the year. Such a trend would of course lower further the annual working hours per member of the labor force. This annual average fell from 3,400 in 1860 to 1,923 in 1963, while the annual hours of work per person in the population fell from 1,137 to 780.

2. *Changes in Worklife Expectancy*

In addition to the 1,200 hours of leisure per year during his worklife, a substantial increase in free time is now available at the beginning and end of man's labor force experience. Of the 18½ years of added life expectancy about 9 are spent outside the labor force, primarily in increased education and training and in retirement. In his lifetime (assuming no further increases in free time) the male born in 1960 will thus enjoy as much as 18,000 hours of leisure from not working during these 9 years, plus approximately 50,000 added leisure hours during worklife (1,200 hours per year during a worklife of 41.4 years), or 68,000 hours in total (the equivalent of 34 work years of 2,000 hours each).

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[17] James N. Morgan, et al., *Income and Welfare in the United States* (New York, 1962), ch. 21.

[18] Long, *op. cit.*, p. 140.

Since his worklife expectancy is longer, however, he will nevertheless work more hours than his earlier counterpart. According to a rough calculation,[19] a male born in 1900 would have worked a varying workweek (through 32.1 years of worklife) and would have rendered approximately 76,000 hours of service. The male born in 1960 who, let us assume, will work 40 hours per week 50 weeks of the year for 41.4 years will work 82,800 hours during his lifetime, or about 6,800 hours longer than his grandfather. Of course, these extra hours will have to support a proportionately greater increase in the length of time lived after entering the labor force.

Needless to say, the assumption that leisure-work patterns will remain unchanged during the next several decades seems at present unwarranted. The extra 6,800 hours of work arising from increased life (and worklife expectancy) may therefore not continue to be rendered. Lowering of the retirement age could easily eliminate this differential; in fact, the decade of the 1950's saw the first decline in length of working life for men in the United States. The male's life expectancy at birth increased 1.1 years (from 65.5 to 66.6 years), but worklife expectancy fell by half a year. This decline, resulting from a marked decrease in the labor force participation rates for older men and a small rise in the age of entry, when added to the extra year of life, raised the average number of years outside the labor force by 1½ years in the decade.[20]

Continuation of the drive for early retirement will of course increase the amount of leisure accruing at the end of life. It seems very likely that the pressure of unemployment, particularly among teenagers, will lead to increases in training programs for youth, thereby postponing significantly the age of entry to the labor force. Worklife may gradually come to be compressed within the age span of, say, 20 to 60.[21] The bunching of free time at the beginning and end of worklife poses certain questions not raised by an increase in leisure in the form of a shorter workweek. In particular, the flow of income is uninterrupted by a shorter workweek or an increase in vacation time; by contrast, earned income ceases upon retirement, and total income usually drops sharply. Leisure in this form is less appealing, therefore, if for no other reason than the accompanying income decline. Until retirement benefits are substantially increased, retirement will continue to be resisted. And for many persons this resistance will continue even if benefits are improved, since complete withdrawal from the job requires adjustments of some magnitude.

C. Potential Growth in Leisure

The increase in nonworking time that has characterized the American economy during the 20th century has in some degree reflected preferences for leisure as compared with income. In broad terms, the summary statement that about two-thirds of the century's productivity gains have been taken in the form of goods and one-third in free time suffices, although this statement alone obscures important issues such as the forms leisure has taken (and the extent to which these forms were in accord with workers' preferences), the distribution of nonworking time among the population, and the offsets against this freed time; e.g., longer commuting time to work. If, however, society has taken roughly a third of its increase in output potential in the form of leisure, the alternative statements that present leisure (as compared with that available in 1890) is "worth" approximately $314 billion, or that GNP which includes the value of leisure as well as the value of goods and services is about $941 billion (instead of $627 billion), provide crude estimates of the dollar value of our growth in leisure. Kuznets' estimates, noted elsewhere, indicate that if account is taken not only of the increase in material goods and services but also of the amount of leisure created, per capita growth in the economic value of output has not slowed down significantly.

Of more importance for present purposes, perhaps, is the question of the possible growth of leisure in the future. Long-range projections of the growth in nonworking time in total have not been made, perhaps because of the difficulties inherent in anticipating man's future elasticity of demand for goods in terms of effort. Despite great public interest in particular issues—shortened workweek, early retirement, etc.—which will determine the pattern into which leisure will fall, the potential magnitude of our leisure component has received little explicit attention.

The dimensions of future leisure can be indicated under varying assumptions as to growth in productivity and preferences as between goods and leisure. In table 3, the 1965 projections of GNP made by the National Planning Association are used, the basic assumptions being: Between 1963-85, the growth rate will be 4.1 to 4.2 percent per year; population will grow by 1.5 percent annually; and unemployment will average 4.5 percent. However, in order to show potential GNP on the assumption of no change in working time—NPA estimates GNP on the basis of a decline in working time of one-half to 1 percent per year—

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[19] In calculating average hours per week. the following estimates are used: For the years 1915–24, the 1920 average is assumed; the years 1925–34, the 1930 average; the years 1935–40, the 1940 average; for 1941 and 1942, an average of 46 hours is assumed, while the data for 1943 through 1947 and thereafter are annual data. Worklife expectancy for the male born in 1900 was 32.1 years, and a workyear of 52 weeks is assumed.

[20] Seymour Wolfbein, *op. cit.*, p. 1.

[21] Juanita M. Kreps, "Economic Implications of a Shortened Worklife," in P. From Hansen, *Aging With a Future* (Munskgard, 1964), pp. 507–512.

TABLE 3. PROSPECTIVE GROWTH IN PRODUCTIVITY AND POSSIBLE USES OF RELEASED TIME

Year	Possible increases in real GNP (1960 dollars)		Alternative uses of potential nonworking time					
							Education and training	
	GNP (billions)	Per capita GNP	Total number of years	Retirement age	Length of workweek (hours)	Vacation time (weeks)	Labor force retrained [1] (percent)	Years of extended education
1965	$627.3	$3,181		65 or over	40	3		
1966	655.6	3,280	2,245,542	65	39	4	2.9	1.2
1967	685.6	3,382	4,655,526	63	38	7	5.0	2.4
1968	707.1	3,490	6,910,648	61	36	7	8.7	3.4
1969	745.3	3,578	8,880,092	59	36	8	11.1	4.2
1970	779.3	3,690	11,263,301	57	34	10	13.8	5.1
1975	973.4	4,307	23,135,642	50	30	16	26.2	9.4
1980	1,250.2	5,059	35,586,729	44	25	21	37.2	13.8
1985	1,544.5	5,802	47,200,158	38	22	25	45.2	17.5

[1] Figures are in addition to the number of workers now trained in public and private programs.

SOURCE: GNP projections and employment data from National Planning Association, Report No. 65-1, March 1965. Labor force data for other computations taken from *Manpower Report of the President*, March 1965, p. 248, table E-2.

the GNP figures used here, corrected for this decline, are slightly higher than the ones derived by the association. Assuming no change in working time, the GNP at projected rates of growth would approximate $1,544,500,000,000 in 1985, about 2⅓ times its present level in 1960 dollars. Per capita GNP would rise from $3,181 to $5,802, or more than 80 percent, despite the increased population size. Less rapid increases in aggregate and per capita GNP than these projections indicate may occur, of course, particularly if shifts in labor force composition (from manufacturing to services) are sufficiently rapid to slow the overall rate of productivity growth.

These increases in total and per capita GNP are possible, then, if working time of roughly 40 hours per week for an average of 49 weeks per year is continued. At the other extreme, if one supposes that all growth, except that amount necessary to hold per capita GNP constant at $3,181, is taken in leisure time, the possible increases in free time are indicated in the remaining columns. The workweek could fall to 22 hours by 1985; or it would be necessary to work only 27 weeks of the year; or retirement age could be lowered to 38 years. If the choice were made to divert the new leisure into retraining, almost half the labor force could be kept in training; if formal education were preferred, the amount of time available for this purpose might well exceed the normal capacity to absorb education.

In deriving these very crude estimates of the dimensions of GNP or leisure for 1985, the following notes are explanatory. Table 4 shows the anticipated size of the employed labor force and the expected population size, 1966 to 1985. The total GNP required to maintain per capita GNP constant is, of course, population times $3,181, the 1965 figure.

Table 5 presents estimates of the total hours worked by the employed labor force, assuming a 40-hour week and a 49-week year; the hourly value of GNP (calculated from projected GNP, assuming a 40-hour workweek and a 49-week year, or 1,960 hours per year); the number of hours of work required to produce the GNP necessary for a constant per capita GNP; and finally, the difference between columns (1) and (3), or the number of hours that would be released from work if people were content to continue on the same GNP per capita during the next two decades.

TABLE 4. PROJECTED EMPLOYMENT AND POPULATION, AND ESTIMATED GNP REQUIRED TO MAINTAIN PRESENT PER CAPITA GNP, 1966–85

Year	(1) Employed labor force (millions)	(2) Population (millions)	(3) GNP required for 1965 per capita GNP (billions)
1966	76.3	199.9	635.9
1967	77.6	202.7	644.8
1968	78.9	205.5	654.7
1969	80.2	208.3	662.6
1970	81.5	211.3	671.8
1975	88.4	226.0	718.9
1980	95.8	247.1	786.0
1985	104.5	266.2	846.8

SOURCE: For employment and population projections, see note to table 3. Estimates of GNP required: Column 2 times $3,181.

TABLE 5. REDUCTION IN WORKING HOURS WITH CONSTANT PER CAPITA GNP, 1966–85

Year	(1) Hours worked at 40 hours per week 49 weeks per year (millions)	(2) Value of goods and services produced per hour	(3) Hours necessary for $3,181 per capita GNP (millions)	(4) Hours released (millions)
1966	149,548	$4.38	145,182	4,401
1967	152,096	4.51	142,971	9,125
1968	154,644	4.64	141,099	13,545
1969	157,192	4.74	139,789	17,405
1970	159,740	4.88	137,664	22,076
1975	173,264	5.62	127,918	45,346
1980	187,768	6.66	118,018	69,750
1985	204,820	7.54	112,308	92,512

TABLE 6. POSSIBLE ALLOCATION OF GOODS AND LEISURE

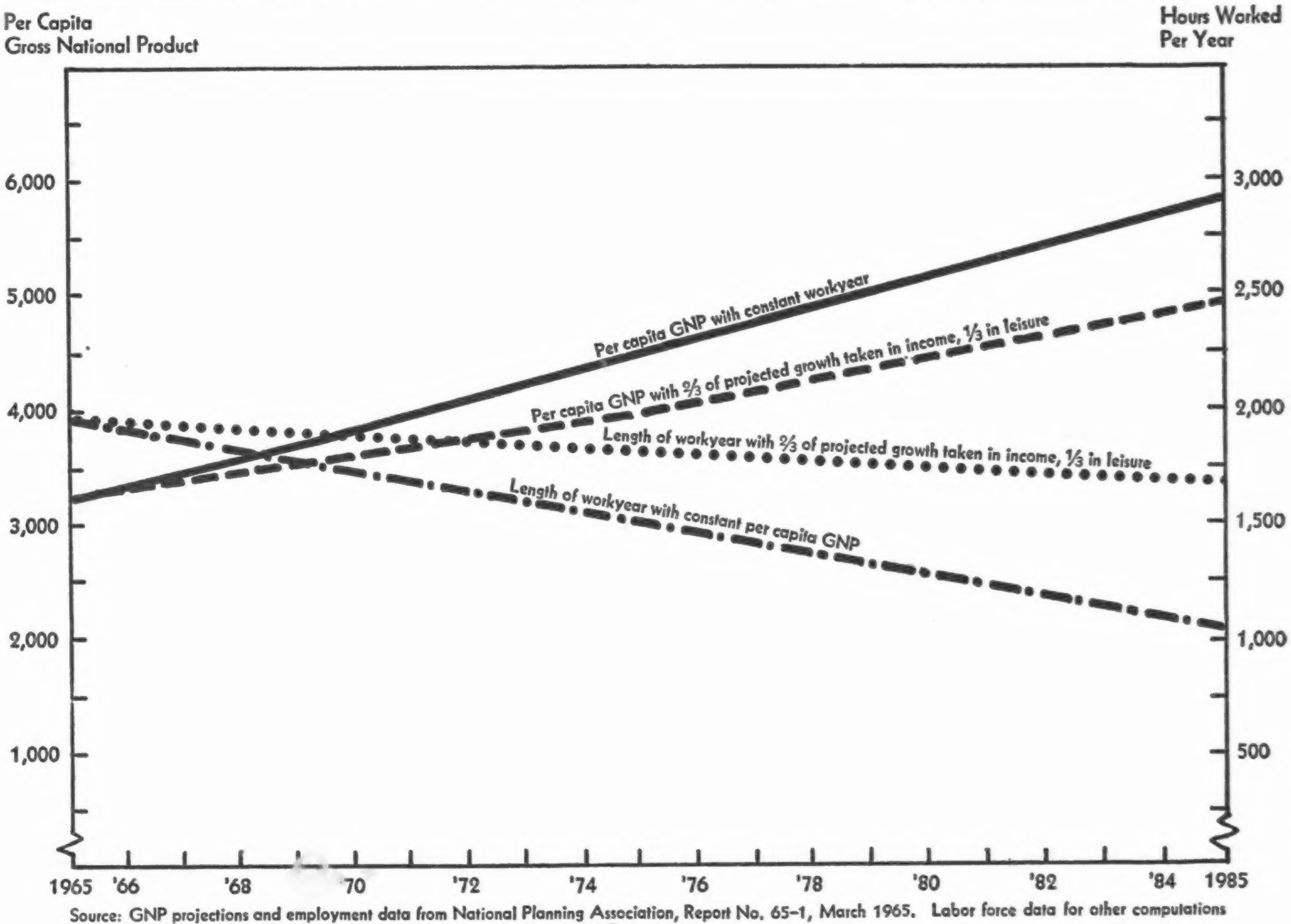
	(1) GNP (billions)	(2) Productivity gains (billions)	(3) Value of goods (⅔ of col. 2)	(4) Value of leisure (⅓ of col. 2)	(5) Per capita GNP	(6) Labor force retrained annually (percent)	(7) Additional vacation (weeks)	(8) Reduction in the workweek (hours)	(9) Hours released for nonworking time (millions)
1966	$649.0	$19.7	$13.1	$6.6	$3,247	1	----------	----------	1,507
1967	670.8	40.8	27.2	13.6	3,315	1	½	----------	3,016
1968	696.3	62.4	41.6	20.8	3,388	1	1	----------	4,483
1969	713.7	82.7	51.1	31.6	3,426	1	1	½	6,667
1970	743.5	107.0	71.3	35.7	3,519	1	1	⅔	7,336
1975	888.9	254.5	170.0	84.5	3,933	1	1	2⅓	15,036
1980(a)	1,095.0	464.2	309.0	155.2	4,413	4.25	1	2½	23,303
1980(b)	1,095.0	464.2	309.0	155.2	4,413	1	2½	2½	23,303
1985(a)	1,321.8	697.7	465.0	232.7	4,928	6.9	1	2½	30,862
1985(b)	1,321.8	697.7	465.0	232.7	4,928	1	4	2½	30,862

SOURCE: See table 3.

It is, of course, not likely that the workweek will drop to 22 hours or that retirement age will decline to 38 years. Nor is it probable that during ing the next two decades workers will continue on their present schedules, thereby taking all productivity gains in the form of a greater quantity of goods and services. If, instead, two-thirds of the output growth accrues as goods and services and one-third as leisure, GNP would rise to more than a trillion dollars by 1980, and to $1.3 trillion by 1985. Per capita GNP would increase to more than $4,400 by 1980 and to approximately $5,000 in 1985 (fig. 5).

The leisure which accounts for the remaining one-third of the growth potential could be distributed in any one way or a combination of sev-

FIGURE 5. *Alternative Uses of Economic Growth Per Capita Gross National Product and Hours Worked, 1965–85*



Source: GNP projections and employment data from National Planning Association, Report No. 65-1, March 1965. Labor force data for other computations taken from Manpower Report of the President, March 1965, p. 248, table E-2.

eral ways; different priorities would be assigned by different persons. If it is conceded that present unemployment is due in some significant degree to qualitative deficiencies in the labor force, however, the first priority might be assigned to job retraining. Hence, a policy decision could be made to retrain a minimum of 1 percent of the labor force annually, taking the necessary time from that freed or released by the growth in productivity. A second order of preference might be an increase in vacation time, at least until an average of one additional week accrues to the worker. By 1968, these two goals—retraining 1 percent of the labor force and increasing vacation time by one full week—could be attained. If after these achievements, some leisure gains are taken in the form of reductions in the workweek, working time per week could start by declining about one-half hour in 1969, the decline increasing to 2½ hours by 1980. (See table 6.)

Alternative allocations of leisure in the period 1980–85 might be as follows: Given a $4,413 per capita GNP in 1980, achieved with a 37½-hour workweek, a 48-week workyear, and providing retraining for 1 percent of the labor force, society could choose to retrain much more heavily (4.25 percent of the labor force per year) or, alternatively, could add 1½ weeks per year in vacation. In 1985, when per capita GNP should reach about $5,000, the choice could be between retraining almost 7 percent of the labor force annually or taking an additional 3 weeks of vacation. Obviously, other choices could be made, involving a further reduction in the workweek, a lowering of retirement age, or an increased educational span for those entering the labor force.

The relevant considerations are at least threefold: One, the total amount of free time made available by the anticipated improvements in output per manhour is extremely great, even when allowance is made for quite rapid rises in real GNP or even in per capita real GNP. Two, the allocation of this leisure is in itself quite important, given the different degrees of utility man may associate with different forms of leisure. Three, the distribution of leisure, being quite unevenly spread over the entire population, requires further consideration. For although the unequal distribution of income among persons has received great attention, it might well be true that that portion of economic growth accruing to man in the form of leisure has in fact been apportioned much less evenly than income. Questions relating to the total volume, the forms, and the distribution of leisure are of some significance in estimating future potentials for growth in output, and particularly in determining the composition of that output.

III. Work Versus Leisure: Traditional Views

Although time has in the past often been discussed as an economic constraint, recent interest in the scarcity of time appears to have grown.[1] "In an economic as in a philosophical or poetic sense," wrote George Soule a decade ago, "time must now be regarded as the scarcest of all the categories of basic resources."[2] The increased efficiency of time made possible by technology has been more than offset by growth in the demands on time, and few Americans have time hanging heavy on their hands. The more successful the process of automation, the scarcer will be time relative to the other resources—land, labor, and capital.

Mr. Soule's thesis appears to be the reverse of the commonly accepted notion that increasing efficiency in the production process is releasing an abundance of time into the hands of workers who are ill equipped to find leisure outlets. In the Nation's beginning, land and natural resources were plentiful while labor and capital were relatively scarce. But with the growth of population, labor has become abundant; unemployment, not labor shortages, is the common problem. Capital, too, has grown in quantity and efficiency, and with the help of technology some of the Nation's natural resources are being utilized with such efficiency that land provides no present constraint on the output of food and fibers, but permits instead the production of unsalable surpluses.

Even if society reached the position of needing no labor at all—if all time were free of work—time would remain scarce in relation to all its potential uses. Since time to consume goods is finite, the demand for goods is limited, too, to the total amount a population can use in, say, a year. Technology thus makes goods ever more abundant and makes free time more plentiful, conceivably up to the limit of 365 days a year. Time cannot be increased beyond this quantity, nor can the volume of goods consumed increase beyond what can be consumed in this limited time. But though time free of work is limited, it nevertheless is the gain man makes through technology. The pressing questions, Professor Soule concludes, have to do with the distribution of this nonworking time over the range of man's needs, many of which, not being met through the market system, do not carry price tags.

The notion of the scarcity of time is also emphasized by Wilbert E. Moore, who notes that "in the world of commonsense experience the only close rival of money as a pervasive and awkward scarcity is time."[3] Time and money are not necessarily interchangeable, however; in many instances, groups of people (the unemployed, for example) may not be able to transform time into goods. It follows that time may have little or no value in certain cases. Defining leisure as discretionary time, Mr. Moore discusses the question of why leisure is now considered a problem. For nonlabor force participants, or unemployed persons, the difficulty arises from having too much time. But for employed members of the labor force, leisure is a problem where work is a problem. The supply of time exceeds its demand for persons whose interests are narrowly limited, and these people are likely to suffer, as well, some alienation from work. By contrast, people who genuinely like their work are prone to have longer workweeks and to feel pressed in finding enough time to do all the things they find interesting. A "perceived scarcity scale of time," the author concludes, might be a very sensitive index to the extent of an individual's integration into the social order.[4]

A. Leisure Versus Goods

Given the scarcity of time, the demand for leisure can be treated in the same manner as the demand for goods. Faced with the problem of allocating his time between leisure and goods, the individual will continue to work until the "advantages to be reaped by continuing seem no longer to overbalance the disadvantages."[5]

In indifference analysis, the worker maximizes his satisfaction with that combination at which the marginal rate of substitution of leisure for wage goods equals the ratio of the price of leisure to the price of wage goods. This equilibrium position is illustrated in figure 6. At P, the worker will take OA in income and OB in leisure. Given the current distribution of leisure, this implies approximately 128 hours of free time per week, or a 40-hour workweek.

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[1] See, for example, G. L. S. Shackle, *Time in Economics* (Amsterdam, 1958), and his list of substantive discussions of expectations and uncertainty in economics, pp. 62–63.

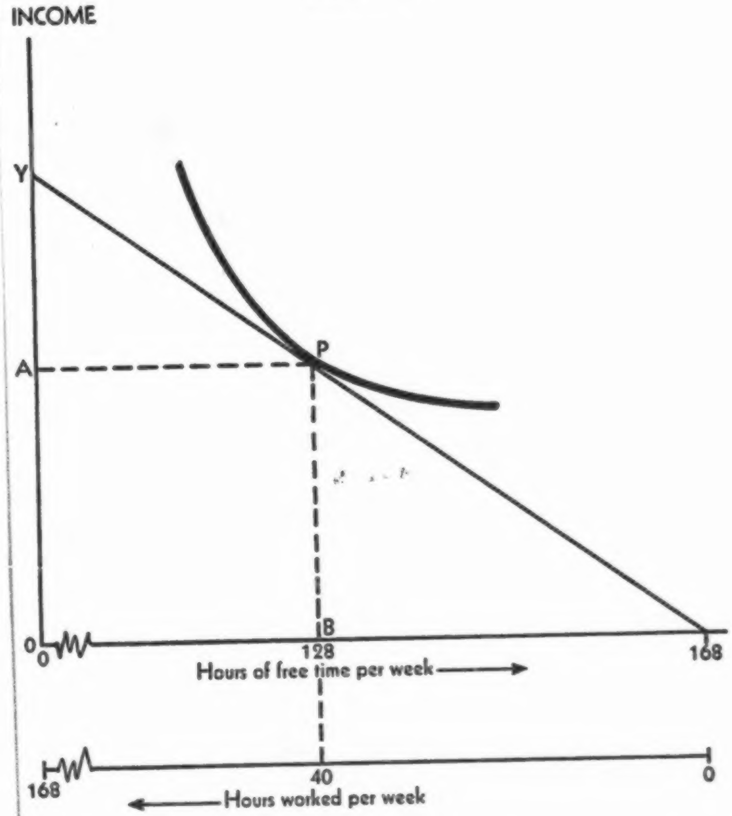
[2] George Soule, *Time for Living* (New York, 1955), p. 99.

[3] Wilbert E. Moore, *Man, Time, and Society* (New York, 1963), p. 4.

[4] *Ibid.*, pp. 38–39. See also Arnold S. Feldman and Wilbert E. Moore, *Labor Commitments and Social Change in Developing Areas* (New York: Social Science Research Council, 1960), p. 64.

[5] Alfred Marshall, *Principles of Economics* (London, 9th ed., 1961), p. 527n. On the economics of time allocation, see G. S. Becker, "A Theory of the Allocation of Time," *Economic Journal*, vol. 75, Sept. 1965, pp. 493–517, which appeared after this paper was completed.

FIGURE 6



If income increases, the individual has three alternatives. He can continue to work 40 hours, taking the entire amount in additional income, or he can now supply less labor and demand more leisure, or conceivably he could work more. If the worker prefers to take the increase in income, then, as indicated in figure 7, he would move from P to a new equilibrium position at P′. Previously the maximum attainable income was OA; now it is OA′. If the worker prefers to continue working 40 hours per week, then income will rise to OA′.

On the other hand, it is possible that the individual may prefer to work less than 40 hours after an increase in the wage rate. In such a case (fig. 8) free time would increase from OB to OB′, or say from 128 to 133 hours of free time per week. Income would increase to OA′. Income at this equilibrium, P′, is less than income OA′ in figure 7, but greater than initial income OA.

Finally, the worker could increase the number of hours he works. Figure 9 illustrates this possibility. The new equilibrium indicates that the worker has increased his workweek by BB′ hours. P′ indicates a preference for OA′ of income and OB′ of leisure. Hours worked have increased by BB′ (or say, to 45 hours per week) while income has increased by AA′.

FIGURE 7

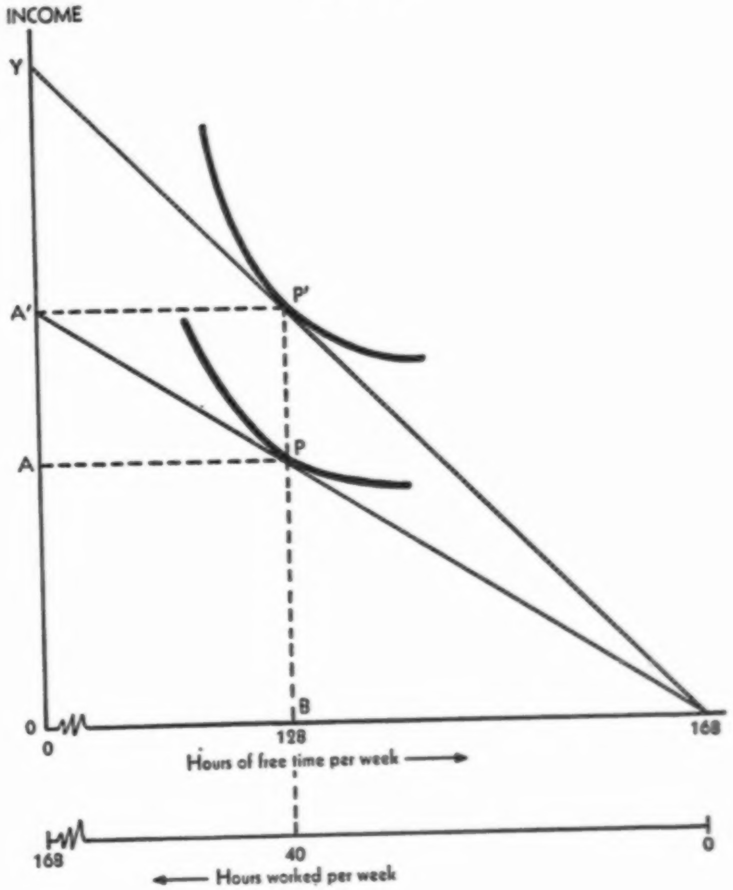


FIGURE 8

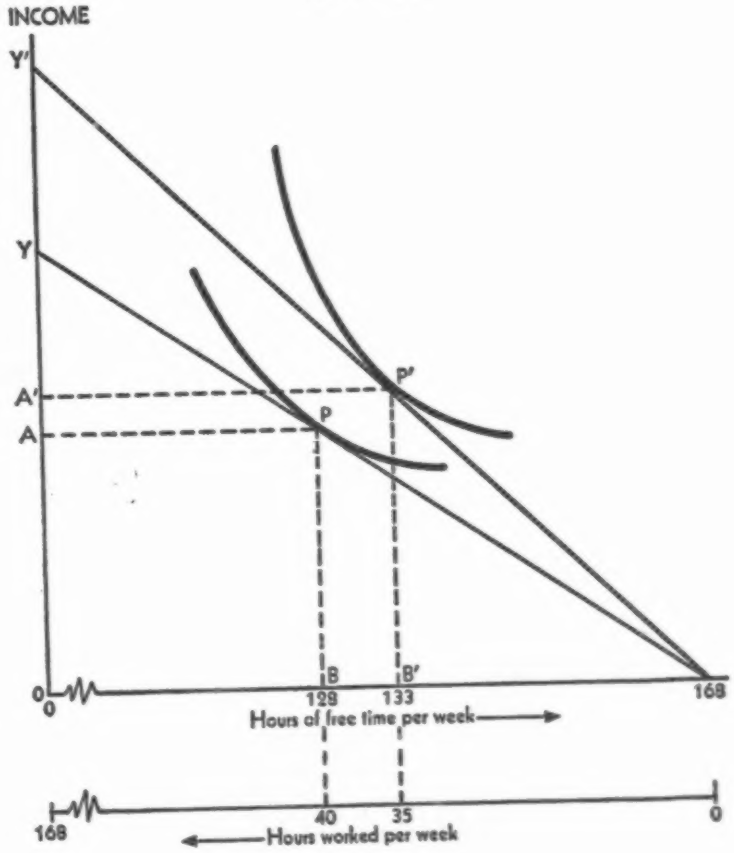
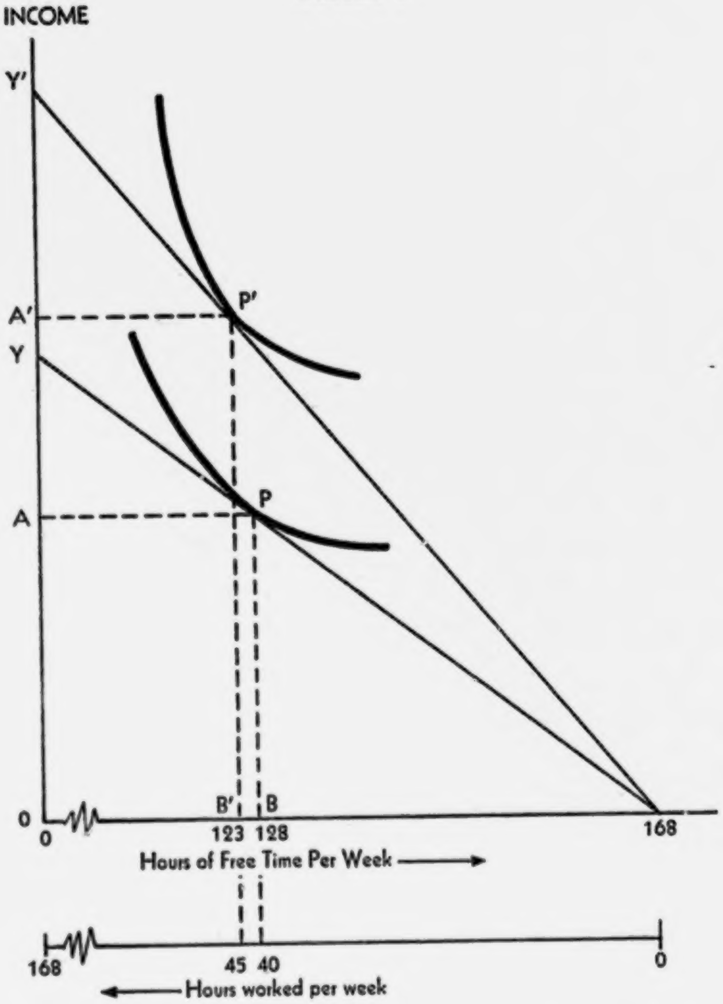


FIGURE 9



1. *The Supply of Labor and the Demand for Leisure*

Using a different approach, the demand for leisure may be viewed as the inverse of the supply of labor.[6] Since each person has a fixed amount of time (168 hours per week), an additional hour of leisure can be obtained only by a reduction of 1 hour in the amount of labor offered. Assuming that a minimum number of hours must be allocated to sleeping, eating, dressing, etc., one author has noted that there are approximately 91 hours per week remaining to be divided between work and leisure.[7] Even if one allows an average of 2 hours per day for travel to and from work, the full-time worker, thus, has almost twice as many hours available for work as he normally spends on the job. Although it cannot be argued that the extra 35 to 40 hours of nonworking time is "free" or uncommitted,[8] it would nevertheless be possible to draw into work a significant portion of this extra time, given adequate incentives.

The relationship between income incentives (wage rates) and the quantity of labor offered has concerned economists for several centuries. The major problem has to do with the supply curve of labor—specifically, the question of whether the quantity of labor varies directly or indirectly with the wage rate. If there exists a positive relationship, i.e., a positively sloped curve, then higher wages will call forth more effort, while lower wages will operate to reduce the supply of effort. Conversely, a negative relationship, or a negatively sloped function, indicates that higher wages will reduce the supply of effort, while lower wages will increase the number of hours worked.

As a rule, the English mercantilists believed that the supply curve was negatively sloped, reasoning that a man would work only enough to provide sustenance.[9] Hence when wages were low, hours worked per week were long; when wages were high, hours were shorter. For instance, Thomas Manly declared that "the men have just so much more to spend in tipple and remain now poorer than when their wages were less . . . ."[10] Josiah Child observed of the poor that "in a cheap year they will not work over 2 days a week, their humour being such that they will not provide for a hard time but just work so much and no more as may maintain them in that mean condition to which they have become accustomed."[11] Reminiscent of the mercantilist attitude, Arthur Young asserted that "Everyone but an idiot knows that the lower classes must be kept poor or they will never be industrious . . . . They must be in poverty or they will not work."[12]

Classical economists had little to say on the matter of whether there was a negative or positive relationship between hours worked and the wage rate. The classical economists were not equipped with a theory of marginal utility and, as a rule, did not consider this theoretical question. At the time Adam Smith was developing his views, it was widely believed that increases in wages would diminish the supply of effort.[13] Smith attempted to combat the prevailing views of the mercantilists by arguing that high wages evoked a greater amount of effort than did low wages.[14] He observed that "Where wages are high, accordingly, we shall always find the workmen more active . . ."[15] He further noted that the majority of workmen, when liberally rewarded, are likely to overwork and threaten their health.[16]

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[6] See H. G. Lewis, "Hours of Work and Hours of Leisure," *Proceedings, Industrial Relations Research Association*, vol. 9 (1956), p. 197.

[7] G. F. Break, "Income Taxes, Wage Rates, and the Incentive to Supply Labor Services," *National Tax Journal*, vol. 6 (December 1953), p. 340.

[8] Sebastian de Grazia argues that a very small proportion of the American man's time off the job is actually free time, since he must spend many hours in work around the home, commuting, etc. See his *Of Time, Work, and Leisure* (New York, 1962).

[9] The review of opinion which follows is a summary of the analysis by J. J. Spengler in "Product-Adding versus Product-Replacing Innovations," *Kyklos*, X (Fasc. 3, 1957), pp. 267–277.

[10] Thomas Manly, "Usury at 6 Percent" (1661), p. 11; quoted in Paul H. Douglas, *The Theory of Wages* (New York: The Macmillan Co., 1934), p. 270.

[11] Josiah Child, *A New Discourse on Trade* (6th ed.), p. 12; as quoted in Paul H. Douglas, *op. cit.*, p. 270.

[12] Arthur Young, *Eastern Tour*, vol. IV, p. 361, quoted in Paul H. Douglas, *op cit.*, p. 270.

[13] Edgar S. Furniss, *The Position of the Laborer in a System of Nationalism* (New York, 1920), chs. 6 and 7, and Lujo Brentano, *Hours and Wages in Relation to Production* (New York, 1894), pp. 2–7.

[14] Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (Modern Library ed., New York, 1937), pp. 81–86, 164, 271–272.

J. B. Say repeated Smith's argument that a liberal wage encouraged industry.[17] McCulloch believed that "hours of work are gradually lessened" when the "demand for labour is brisk and increasing," [18] because so long as wages were high, workers might have a little additional time at their disposal and still earn enough to satisfy their needs and desires to accumulate (even when their level of living is rising).

Malthus, as one would predict, argued that a negative relationship existed between wages and hours worked. When subsistence could be maintained with 2 or 3 days' labor per week, the laborer would work no more, but be content with his lot.[19] Jevons emphasized the irksomeness of work. He argued that an increase in output and wages per hour would be accompanied by a diminution in the number of hours worked, and reasoned further that with a higher wage the worker would receive more pleasure by relaxing than by consuming additional wage goods.[20] However, Jevons qualified his argument with respect to professionals, recognizing that the irksomeness of their labor increased much less rapidly than that of other workers.

Marshall's position appears to be in agreement with that taken by Smith and Say. He concluded "that increased remuneration causes an immediate increase in the supply of efficient work." [21] Again, Marshall commented that "it is broadly true that the exertions which any set of workers will make rise or fall with a rise or fall in the remuneration which is offered them." [22] Marshall qualified this general statement by noting that many workers found additional hours increasingly irksome. Relaxation and leisure were coming to be valued more highly, with the result that the willingness to work long hours was beginning to decline. Chapman reasoned somewhat similarly when he noted that the strain per hour was increasing. As wages increased, the value of leisure was considerably enhanced.[23] Pigou apparently accepted a negative association between wages and hours worked; he reasoned that a tax on income increased the marginal utility of money but not the marginal disutility of the individual's work.[24] Since the marginal utility of money was increased, this tended to increase the number of hours worked.

In recent discussions concerning the slope of the supply function, alternative opinions are as divided as in the past. Discussions of current interest frequently center about the effects of taxation on work incentives.

> The income tax is a tax on effort, whereas a sales tax is a tax on consumption, which can be avoided insofar as income is saved. The former diminishes effort, the latter diminishes consumption or possibly encourages more effort to maintain a given consumption.[25]

G. F. Break has assumed the leadership in arguing that the supply curve is either negatively sloped or highly inelastic. He believes that fixed commitments on the part of workers act to produce a negatively sloped curve. Some workers face commitments with respect to rigid work patterns; some are committed to achieving certain goals. It has also been observed that many consuming units demand a certain level of living that must be maintained.[26] The pressures of these commitments force the worker to render a certain number of hours at any given wage rate, thus tending to make the supply curve inelastic, or else cause him to demand a certain level of income, which can be maintained with fewer hours of work as the wage rate rises.

The indifference curve technique [27] makes it possible to distinguish between the different income and substitution effects given the assumption as to whether a negative or a positive supply curve is applicable. Assuming a positively sloped function, it follows that with an increase in the wage rate the substitution effect leads to less use of leisure, since it is now more expensive, while the income effect operates to increase the consumption of all goods, leisure included. Following our assumption of a positively sloped function, the substitution effect must outweigh the income effect since higher wages, given the conceptual framework, always call forth more effort. On the other hand, if the wage rate declines, the quantity of leisure demanded increases, the substitution effect again being dominant.

Conversely, in the case of a negatively sloped supply curve a wage rate increase decreases the amount of leisure demanded, since it is now more expensive. Again, however, the income effect increases the amount of leisure demanded because additional income calls for additional consumption of all goods. Under the stated condition of a negatively sloped supply function, the income effect will dominate; fewer hours are offered as the wage rate rises. Given a decrease in the wage rate, however, the income effect will dominate and reduce the consumption of all goods, leisure included.

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[15] *Ibid.*, p. 81.

[16] *Ibid.*, pp. 81–82.

[17] J. B. Say, *Traité d'économie politique* (Paris, 1841, book II, ch. 7, sec. 4).

[18] J. R. McCulloch, *Principles of Political Economy*, 5th ed. (Edinburgh, 1864), pp. 142–144, 328, 330, 339–348.

[19] T. R. Malthus, *An Essay on the Principles of Population* (London, 1826), pp. 368, 379, 424–425, 535.

[20] W. S. Jevons, *The Theory of Political Economy* (London, 1881), pp. 168–170.

[21] Alfred Marshall, *Principles of Economics* (London: Variorum edition, 1961), pp. 140–43, 526–529, 680–696, 720–721.

[22] *Ibid.*, pp. 140–143.

[23] S. J. Chapman, "Hours of Work," *Economic Journal*, XIX (1909), pp. 354–373.

[24] A. C. Pigou, *A Study in Public Finance* (London, 1929), pp. 83–84, and *The Economics of Stationary States* (London, 1935), pp. 163–164.

[25] W. A. Morton, "A Progressive Consumption Tax," *National Tax Journal*, vol. 4 (June 1951), p. 162.

[26] See James Duesenberry, *Income, Saving, and the Theory of Consumer Behavior* (Cambridge, 1949), p. 115.

[27] See J. R. Hicks, *Value and Capital* (Oxford, 1937), pp. 36–37.

2. *Empirical Evidence*

Since the turn of the century wage rates have increased and so, too, has the amount of leisure time. Through the long run, therefore, it is clear that workers have devoted less of their time to work as the remuneration for work rose, or stated differently, they have demanded more and more free time, despite the fact that each additional hour of free time became more expensive in terms of goods foregone.[28]

a. *The Demand for Income.* At least two recent studies have underscored the notion of a highly inelastic or a negatively sloped supply function. Break interviewed 306 accountants and solicitors, selected because of their ability to control their hours and because they were subject to high marginal and average tax rates. He discovered that the disincentive effects of the income tax had little effect on effort expended.

> When you get right down to it, I am working as hard as I ever worked. I complain bitterly about how little I am allowed to keep of every pound I earn, but I go on doing the work just the same.[29]

The author notes that several factors will tend to cause workers to offer the same amount of labor, despite the imposition of income taxes: the tendency toward larger families, which increases commitments; higher divorce rates; increasing demand for consumer durables; the entrance of wives to the labor force, notwithstanding higher marginal tax rates; greater domestic and foreign travel which stimulates demand; greater urbanization, with the "bandwagon" effect on consumption patterns; decreasing flexibility of the individual's working habits, which reduces the individual's propensity to change his working hours in response to a tax increase.

A recent analysis of hours of work in the United States used cross-sectional data in an attempt to explain the effect of economic and demographic factors on the number of hours worked by different groups. Holding age, education, and color constant, the author found that adult males with higher hourly earnings worked fewer hours per week than men with lower rates of pay.[30] By contrast, Harold Wilensky's study of the distribution of leisure indicates that being high-income (as well as being self-employed or being Jewish) raises the propensity for long hours. One-third of the high-income men he studied (those earning $10,000 and over) logged 55 hours or more per week, as compared with one-fifth of the men earning less than $10,000. He also found, however, that the differences in work schedules within income strata were extremely wide.[31]

The question of whether workers prefer more leisure or more goods (or the desired proportions in which the two are to increase, with a given rise in productivity) requires further examination, particularly in the light of current attempts to reduce the workweek, lower retirement age, establish increased vacations based on seniority, etc. For there is evidence that Americans are strongly "thing minded" rather than leisure oriented, and that the drive for a shortened workweek springs primarily from a desire to increase jobs, rather than a desire for more leisure.

Our high levels of consumption have long distinguished us from European consumers. Industry in this country caters to the taste for variety in style and form, and mechanical and electrical gadgets, household appliances, automobiles, etc., are readily available in the market. As incomes rise, the consumption of these goods rapidly becomes a part of the worker's standard of living; today's luxuries are tomorrow's necessities. Ruth Mack demonstrates the high propensity to consume by calculating the income elasticity for various commodities. Using Kuznets' data, she finds that a 1-percent increase in income produces a 0.95-percent increase in consumption of perishables; for durables a 1-percent rise in income produces a 1.15-percent increase in consumption, and for services the rise is 1.16 percent.[32]

In explaining the high level of consumption, several factors have been cited: The American housewife's demand that her home be as up to date and shining as possible; the social status conferred by the ownership of goods, particularly consumer durables; the rapid rate of innovation and change in models, etc. The tendency for saving to remain a fairly constant percentage of income has been noted by economists,[33] although it has also been suggested that the composition of future consumption may reflect very rapid expansion in the services sector.[34] One further indication of the desire for goods rather than leisure is the growth in the number and proportion of married women in the labor force.[35]

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[28] See Clarence D. Long, *op. cit.*, particularly chs. 1, 2, and 13.

[29] G. F. Break, "Income Taxes and Incentives to Work," *American Economic Review*, vol. 47 (September 1957), p. 548.

[30] T. A. Finegan, "Hours of Work in the United States: A Cross-Sectional Analysis," *Journal of Political Economy*, vol. 70 (October 1962), pp. 452–470.

[31] Harold T. Wilensky, "The Uneven Distribution of Leisure," *Social Problems*, vol. 9 (1961–62), pp. 32–56.

[32] Ruth Mack, "Trends in American Consumption and the Aspiration To Consume," *American Economic Review*, vol. 46 (May 1956), p. 57.

[33] See Simon Kuznets, *National Products Since 1869* (New York, 1946); James Duesenberry, *op. cit.*; and Milton Friedman, *A Theory of the Consumption Function* (New York, 1957).

[34] See Ruth Mack, *op. cit.*, also Nelson Foote, "Discussion" (Shortening the Work Week), *American Economic Review*, vol. 46 (May 1956), p. 227.

b. *The Demand for Leisure.* A high propensity to consume does not, however, prevent workers from demanding more free time along with their consumer goods. In fact, the tendency for increased leisure to generate an increase in the demand for goods is frequently applauded.[36] Denney has indicated the extent of growth in (and the changing composition of) leisure goods, lamenting the fact that theater performances, books, magazines, and the arts in general have failed to maintain their relative share in the overall increase in leisure-related services. Sales of television sets, automobiles, fishing and skindiving equipment, and such goods have boomed.[37] Later data reported by Peter Henle reveal quite large increases in the consumption of leisure services, such as oversea travel, visits to museums, parks, etc., publication of new books, and the numbers of copies of paperbound books sold.[38] George Fisk's study of leisure-spending behavior concluded that consumers were highly responsive to price and income changes. Using data from the 1950 Survey of Consumer Expeditures, he found that a 1-percent increase in the price of recreation was accompanied by a drop of 1.26 percent in expenditures for recreation. For each 1-percent increase in constant-dollar income, recreational expenditures rose 0.88 percent.[39]

Without regard to the particular types of leisure goods demanded, it is clear that growth of free time does stimulate the demand for goods and services in total. Oddly enough, this fact has not often been used to support pleas for reduced working time. In fact, the case for reducing the amount of time spent on the job (which have been, for the most part, arguments for reductions in the number of hours worked per week) has given very little attention to the benefits of the leisure itself. Increases in the amount of leisure, as such, are seldom defended. Instead, the defense of reduced working time rests on the need to create additional jobs, thus implying not that there will be more free time but rather that the free time, like the work itself, will be spread more evenly over the entire labor force, including, of course, the unemployed.

It is primarily the worker's fear of unemployment that prompts him to press for a reduced workweek, and not a desire for increased leisure. A trade union conference on shorter hours concluded in 1957 that—

> . . . the most significant single factor influencing the unions [in their drive for a shorter workweek] has been the desire to minimize unemployment when it threatens as a result of either economic or technological development.[40]

c. *Customary Leisure, Maximum Income.* While it is clear that the push for reduced working time springs primarily from a desire to spread work, it does not follow that additional leisure has no value. What does seem apparent is the fact that in the absence of the unemployment threat workers would place a higher value on additional goods than on additional leisure, and that given a choice between an increase in hourly wage rates (commensurate, say, with the productivity increase) and a reduction in working time, they would choose the former. Since the demand for a reduced workweek is usually a demand for the same weekly pay for a reduced number of hours, it is in effect a demand for higher hourly rates, or else it involves the payment of enough overtime at least to maintain the same weekly wage.

If at present the 40-hour week is not particularly onerous for the worker, but he does feel that his income is inadequate, his demand for leisure beyond 128 hours per week is highly inelastic with respect to income. For workers who have become accustomed to being at work (and whose colleagues typically work) the standard number of hours, the attraction of more time off apparently has much less appeal than an increase in income. Hence, if wage rates are rising in keeping with productivity, the worker's true preference can be illustrated by a perfectly inelastic demand for leisure (or supply of effort). The concept of a "fair" or "customary" workweek may therefore preclude the gradual acceptance of a portion of productivity gains in the form of leisure, the resistance being removed only when some major policy decision changes the pattern of working time.

At least two questions can be raised regarding the hypothesis that the worker's demand for leisure is extremely inelastic with respect to wage increases, once he is working the customary number of hours: One, why would the quantity of leisure demanded not decline again (the backward-sloping supply curve of labor) at high wage rates? Obviously, there are many workers who work overtime, others who take second jobs, etc., indicating that leisure is often sacrificed for income by persons whose primary job takes the customary 40 hours. The extent of moonlighting, discussed below, is, of course, significant, but the fact remains that most workers have only one job. And except for certain professions, actual hours worked conform pretty closely to scheduled hours. A second question arises: What (if not a wage rate change) brings about a change in the customary workweek? When will the customary number of hours drop from 40 to 38, for example, and why?

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[35] See Vera C. Perrella, "Marital and Family Characteristics of Workers in March, 1963," *Monthly Labor Review*, vol. 88 (March 1965, p. 260.

[36] See, for example, "Thirty Billion for Fun," from *The Changing American Market*, by the editors of *Fortune* (Garden City, 1955), ch. 10, as reprinted in Larrabee and Meyersohn, *op cit.*, pp. 161–172.

[37] Revel Denney, "The Leisure Society," *Harvard Business Review*, vol. 37 (May–June 1959), pp. 57–59.

[38] Peter Henle, "The Quiet Revolution in Leisure Time," *Occupational Outlook Quarterly*, vol. 9 (1965), pp. 5–9.

[39] George Fisk, "Toward a Theory of Leisure Spending Behavior," *Journal of Marketing*, vol. 24 (Oct. 1959), pp. 51–57.

[40] "Trade Union Conference on Shorter Hours of Work in the United States," *Internatioal Labor Review*, vol. 75 (June 1957), p. 558.

Legislation specifying penalty rates for hours over 40 led to a gradual reduction in overtime, since it was expensive. However, there has been quite a bit of speculation as to whether a statutory reduction in the workweek would create new jobs, or whether the amount of overtime would increase instead. Comparative wage-cost data are not available, but in negotiated plans the stated purpose is often that of increasing actual hourly rates. When the Typographical Union established a 35-hour week in 1963, it was

> . . . understood that the sole effect of reducing weekly hours of work under this contract [was] to increase the hourly rate for each shift, and in consequence cause overtime rates to rise.[41]

In summary, there appears to be some resistance to a reduction in the number of hours worked, even on the part of the proponents of a reduced workweek. If a statutory reduction actually occurs, therefore, it may be some time before it comes to be generally accepted and viewed as the customary workweek. Once workers have adjusted their schedules to, say, a 7-hour day, their demand for leisure might well come to be wage inelastic again, much as it appears to be for a 40-hour week. It is easy to imagine, in fact, that given some period of time workers could come to think of a standard workweek of 30 hours as being appropriate, the 40-hour week being remembered in much the way we now think of the 10-hour day.

But these shifts in attitude as to what constitutes the appropriate amount of working time occur only in the long run, and in the future they are likely to be established because of attempts to create jobs, and they will be accepted by the workers as necessary to that end. In the actual initiation of demands for a reduced workweek, the workers' preference for leisure over goods is not a factor; preference would seem to dictate the reverse. The incidence of moonlighting indicates that some workers choose income in preference to leisure. The proportion of the labor force having second jobs was 5.7 percent in May 1963 and 5.2 percent (or 3.7 million workers) in May 1964, with 12 hours per week being the average time spent on the second job.[42] Further evidence of the income preference is found in the competition for overtime hours cited above, which sometimes results in a contractual guarantee of a certain amount of overtime.[43]

Work patterns of the rubber workers are frequently cited in support of the thesis that workers are striving for income, not leisure. During the period in which most of the industry operated on a 6-hour, 6-day week, surveys indicated that 10 percent of the workers had second full-time jobs, and another 30 to 40 percent had additional part-time jobs. The union estimated that as many as 75 percent had moonlighted at some time.[44] If the response of the rubber workers is typical of labor in general, the strong preference for income that would accompany a reduced workweek could result in an increase in hours worked per week, provided second jobs could be found by all workers seeking them.

Labor's revealed preference for leisure, apparent both in legislative proposals and collective bargaining demands, seems to contradict its concealed preference for income. Confronted with persistent unemployment throughout the postwar era and the constant threat of an even higher labor displacement rate as automation proceeds, labor's arguments for reduced working time are understandable. The question of the effect of reduced working time on the aggregate demand for labor is discussed in the ensuing pages.

B. Reduced Working Time and the Creation of Jobs

The demand for a shorter workweek, originating from a fear of job scarcity, is thus offered as a partial solution to the problem of unemployment.[45] Increases in the number of holidays and in the length of vacations, as well as the pressure for early retirement, are also being proposed.

The notion that reductions in working time will result in increases in the number of persons employed is based, of course, on the assumptions that jobs are "freed" by these reductions in the workyear or worklife, and that unemployed persons will be called into employment to fill the newly created vacancies. Heard less frequently is the related thesis that the aggregate demand for labor is increased by increases in purchasing power accompanying the reduced workweek (which occurs without reducing weekly pay and, hence, creates an increase in total purchasing power by the amount of the wages paid to additional employees).[46] Nor is it often argued that a decrease in the workweek will increase productivity;[47] in general, there seems to be agreement that further decreases in weekly hours would have little effect on output per man-hour.[48] Other beneficial effects of reduced hours have been cited: An increase in total labor force size would occur because of the entrance of women, students, and aged persons available for part-time jobs;[49] mobility might be improved as a result of increases in labor force size;[50] much constructive work is carried on by persons during their free time; family and community relationships are improved by growth in nonworking time, etc.[51]

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[41] "Collective Agreement for Newspaper Typographers in New York," *International Labor Review*, vol. 84 (October 1963), p. 421.

[42] Harvey A. Hamel and Forrest A. Bogan, "Multiple Jobholders in May 1962," *Monthly Labor Review*, vol. 86 (May 1963), p. 513, and "Multiple Jobholders in May, 1964," *Monthly Labor Review*, vol. 88 (Mar. 1965), p. 266. A "normal" amount of moonlighting in previous years has been considered 5 percent of the labor force. Since the survey is conducted in May, it does not reflect moonlighting during certain months (e.g., December) when second jobs may be somewhat more prevalent.

[43] See Neil Chamberlain, *The Labor Sector* (New York, 1965), p. 520.

[44] W. I. Ginsburg and R. Bergmann, "Workers' Attitudes Toward Shorter Hours," *Monthly Labor Review*, vol. 79 (Nov. 1956), pp. 1268–1270.

[45] For further discussion, see Melvin W. Reder, "The Cost of a Shorter Work Week," *Industrial Relations Research Proceedings*, vol. 9, (1956), pp. 207–221.

Arguments against reductions in the workweek have been based primarily on the belief that the resulting increase in costs would discourage business expansion and hence impede economic growth, or else lead to higher prices and thus worsen our competitive position in international trade. As a corollary, the argument holds that the demand for workers will increase very little if at all, and hence the purpose of creating additional jobs will not be achieved. Herbert E. Northrup, in opposing bills proposing reductions in the maximum workweek,[52] summarized his detailed statement as follows:

> **I. Although the bills introduced deal with hours and overtime, the issue is employment.**
>
> **II. Economic theory and analysis give little hope that reduction in hours will yield an increase in employment; rather . . . the increased cost incident to a reduction in the workweek would very likely reduce employment and aggravate unemployment.**
>
> **III. Present-day unemployment is structural, involving particular areas and groups . . . . A reduction in hours will not solve the problems of these groups, but, by raising costs, will add more barriers to their employment.**
>
> **IV. Increases in the cost of overtime will not spur employment, but overtime is not a significant factor in the total picture. Instead, as costs increase, such increases could reduce overtime.**
>
> **V. Shorter hours will not increase efficiency, but will probably decrease it. Productivity and economic growth will probably both be adversely affected by shorter hours.**
>
> **VI. Shorter hours could adversely affect research and development.**
>
> **VII. Shorter hours will place a further and, in many cases, insuperable penalty on American industry's ability to compete with foreign competitors. Shorter hours would also adversely affect our balance of payments.[53]**

In much the same vein, Gerhard Colm's analysis of its probable effects leads him to oppose a reduction in the workweek. He argues first of all that workers prefer income to leisure (the evidence being the extent of moonlighting), and that even if additional leisure were desired, paid vacations or sabbaticals which would be used for retraining would probably be preferable to a shortened workweek. Secondly, the increase in labor costs which, under varying assumptions, could range from 6.25 to 12.5 percent for a 5-hour reduction and 10 to 20 percent for an 8-hour reduction would seriously affect American industry's competitive position in world trade. Finally, the geographical and occupational mobility of labor is not sufficiently high to permit the reduction in hours to be evenly distributed among the unemployed. Both Mr. Colm and Mr. Northrup argue that increased job training, in combination with fiscal measures designed to stimulate demand, would be more likely to ease the unemployment problem.[54]

In addition to the discussion surrounding proposals for reductions in the workweek, current attention is being focused on the issue of early retirement, in large measure because of the recent agreement won by the United Automobile Workers. Providing monthly benefits as high as $400 for workers aged 60 or more with 30 years of service, the contract was negotiated in an attempt to provide job openings by offering substantial income incentives to retire. The question of how effective this incentive will be within the automobile industry cannot be answered at present; the number of men who will elect early retirement is a matter of conjecture. However, it is possible to estimate the potential number of retirements that could arise from such plans, if they were extended to all workers who could qualify.

If the terms of the UAW contract were extended to all males (except farmers, farm managers, and professional men) now covered by private pensions, a rough estimate of the numbers of potential retirees thus covered who have 30 years' experience, and hence could qualify for $400 per month at age 60, is shown below.[55]

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[46] See Clyde E. Dankert, "Automation, Unemployment, and Shorter Hours," in Dankert, et al., editors, *Hours of Work* (New York, 1965).

[47] See, however, Clark Kerr, "Discussion" (Shortening the Work Week) *American Economic Review*, vol. 46 (May 1956), p. 221, and Solomon Barkin, *ibid.*, pp. 223–225. Note also that increases in productivity are cited as a reason for reducing working hours, without reference to whether the shorter workweek will in itself raise output per man-hour further. See the statement by A. J. Hayes in *Hours of Work*, Hearings before the Select Subcommittee on Labor of the Committee on Education and Labor, House of Representatives, first sess., part 2, p. 715.

[48] For a recent analysis, see David G. Brown, "Hours and Output," in Dankert, *op. cit.* Edward F. Denison argues that reduced hours will result in reduced output. "As the work year becomes shorter, each percentage reduction in hours entails a progressively greater sacrifice of output. Thus a given percentage increase in aggregate man-hours worked (resulting from a rise in employment partially offset by shorter hours) has meant, and will continue to mean, a progressively smaller percentage increase in effective labor input." See his paper "The Sources of Economic Growth in the United States and the Alternatives Before Us" (New York: Committee for Economic Development,

[49] Clark Kerr, *op. cit.*, p. 221.

[50] Harold G. Halcrow, "Discussion" (Shortening the Work Week), *American Economic Review*, vol. 46 (May 1956), p. 230.
1962), suppl. paper No. 13, pp. 40–41.

[51] For detailed statement stressing the social and economic advantages of gradual reduction in working time, see the testimony of Eli Ginsberg in *Hours of Work*, hearings, cited above, part I, pp. 217–232.

[52] H.R. 355, H.R. 3102, H.R. 3320, and H.R. 1680.

[53] *Hours of Work, Hearings* (part II), *op cit.*, p. 593.

[54] *Ibid.* (part I), pp. 190–202. See also statements by William H. Chartener (part I), pp. 202–216; Clyde E. Dankert (part I), pp. 105–121; Leon H. Keyserling (part I), pp. 122–151; and others, as well as the series of statements produced in part II.

Year	*Potential retirees*
January 1, 1966	344, 264
January 1, 1967	82, 781
January 1, 1968	87, 485
January 1, 1969	91, 717
January 1, 1970	98, 302
January 1, 1971	108, 649

If such an extended scheme became effective on January 1, 1966, the initial impact could be quite large, since covered workers aged 60 through 64 would be eligible to retire. Thereafter, the number reaching the eligibility age would be much smaller. Moreover, these figures indicate the number of potential retirements made possible by the extension of benefits; correction would still have to be made for the fact that some workers would be earning less than the base pay, and others who could qualify for the maximum benefit would not elect early retirement.

The difficulty of estimating how many jobs are "freed" by making early retirement available arises from our lack of detailed knowledge on workers' preferences between leisure in general and income, and more particularly, between leisure in the form of retirement and income during later working life. As A. J. Jaffe has pointed out, little is known about workers' actual preferences for leisure over goods, or vice versa, except that historically, in the American economy, an average 3-percent increase in labor productivity was apportioned as roughly 2 percent in income and 1 percent in leisure up until World War II. If labor productivity continues to grow at 3 percent annually, he suggests a 1-percent decrease in working time, or a 10-percent decrease over a decade, such additional leisure being taken in whatever form is preferred. The conclusion that "since life expectancy in the United States is just a shade over 70 years in 1960 . . . 35 years of work during the course of one lifetime is sufficient"[56] will be applauded in some circles, but opposed in others. Alternative methods of apportioning leisure, under the assumption that in total it will continue to absorb one-third of our productivity gains, were indicated in the preceding section on the dimensions of leisure.

Clearly, the gains from technology have accrued to mankind in the forms of higher planes of living and greater free time. The issue at present turns on the question of the preferred proportions of goods and leisure, true. But the problem of unemployment has obscured somewhat the true nature of the choice, with the result that increasing leisure may come to be regarded primarily as a means of reducing labor force size, despite the evidence that such attempts will do little to solve the problem. Viewed in this manner, free time may increase even if its utility (as compared with the utility of additional goods) is low. What is perhaps even more important, the temporal distribution of the additional leisure, which has received very little attention either by social scientists or policymakers, may have little resemblance to man's actual preferences.

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[55] In 1965 there were 2,753,000 males aged 60–64 in the labor force and another 3,750,000 males aged 55–59. Excluding females and males in three occupational groups (farmers, farm managers, and professionals), approximately 47 percent of the remaining labor force, or 25 million men, are now covered by some private pension plan. Coverage is assumed to be extended to covered men of all age levels. If, among all older men covered, the proportion having 30 years' experience is about the same as the percentage covered by the UAW contract (about 37.5 percent), the potential retirements would approximate the numbers indicated. Labor force data taken from U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings*, vol. 10 (April, 1965), tables A–12 and A–21.

[56] See Mr. Jaffe's statement in *Hours of Work*, hearings (part II), *op. cit.*, pp. 727–732, and his "Population, Needs, Production and Older Manpower Requirements," in Harold L. Orbach and Clark Tibbitts, *Economics of Aging* (Ann Arbor, 1963), pp. 31–40.

IV. Work Versus Leisure: A Reconsideration

The central concern of this chapter is the fitting of alternative activities, mainly "work" and "leisure," within the context of time. When this is done, the limitational role of time, together with the implications of this role, become apparent. Time, however, also functions as a dimension; this role must first be examined.

A. Time as a Dimension

Time is not an input as such, but a dimension of every type of input. While input may be variously defined, it is most usefully denominated a service that flows from various sources of services. The sources differ, of course, but relatively similar sources are usually assembled into sets labeled labor, land, material, capital, personal capital, immaterial capital, such as scientific knowledge, etc., each of which may be divided into subsets. These sets may, however, for some purposes of analysis, be assembled into one all-inclusive set and designated "capital," since the members of each set have in common the property of yielding a stream of services or income over time.[1] The sources, or stocks, of diverse services may be converted into comparable value terms through use of the rate of interest since the services themselves command prices.

Time has always played an important role in economics, implicitly in classical theory and explicitly in neoclassical theory (especially in the works of Marshall, Fisher, and Knight) and in Keynesian and post-Keynesian theory. The concern of this chapter has not, however, been emphasized in these analyses; their emphasis has been upon rates per unit of time, upon degree of adjustment per unit of time, upon time patterns of consumption and production, and upon the implications of futurity.[2] Even so, some of these concerns may be relevant to the present discussion.

The sources of services referred to earlier fall roughly into two categories: (a) Those which, being subject to little or no nonuser and user costs, are nondepletable and permanent; and (b) those which are consumed by user and nonuser costs. These two sources are similar, of course, in that neither will be exploited unless the value of the output, expressed in terms of marginal revenue, exceeds marginal current and relevant variable overhead cost within an operable range. Of pertinence here, however, is the fact that category (a) sources do not erode with the passage of time, whether or not they are in use; whence they may be described as immune to both user costs attendant on use and nonuser costs incident in the absence of use.[3] They are not, however, immune to another cost of nonuse, that of idleness, which consists in the return above cost of what would have been produced had the source been used as fully as economically feasible.

Let us designate such nondepletable source of services S_n; then the flow of services of which the S_n is capable is S_nT where T denotes a period of calendar time of relevantly long length. If the actual temporal rate of use of S_n—call it t—falls short of the realizable maximum, i.e., $S_nt<S_nT$, then S_n is subject to idleness cost, given that the additional revenue realizable appropriately exceeds relevant costs attendant upon the use of S_n. This idleness cost could run as high as $S_n\ (T-t)$; it reflects neglect of the dimension or input of time which continues to flow whether or not S_n is exploited. Illustrative of S_n would be economically exploitable falling water, or wavelengths, since both are usable 24 hours per day at no cost of depletion. Land sometimes is illustrative, though often utilizable only part of a day or year and usually subject to user and/or nonuser costs.

Let us return now to category (b) sources, or those subject to the depleting influence of user and nonuser costs. This category may be subdivided into two: (i) Material agents and (ii) human agents, though the latter resemble somewhat certain components of (i). The material agents are of two sorts, depletable deposits of mineral and related materials, and manmade material capital; the former is subject mainly to user costs, and the latter to nonuser costs as well, especially in a world in which changes in methods and fashions can give rise to a high rate of obsolescence. If we denote category S_d components of (i) in category (b), then waste results when $S_dt<S_dT$, both be-

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[1] On this conception, see H. G. Johnson, *The Canadian Quandary* (Toronto, 1963), chap. 14.

[2] G. L. S. Shackle, *Time in Economics* (Amsterdam, 1958), R. M. MacIver, *The Challenge of the Passing Years* (New York, 1962), chap. 20.

[3] User and nonuser costs were recognized by J. M. Keynes, *The General Theory of Employment, Interest and Money* (New York, 1936), pp. 52–53, 66–73. See also A. C. Neal, "Marginal Cost and Dynamic Equilibrium of the Firm," *Journal of Political Economy*, L, 1942, pp. 45–64; G. Tinter, "The Theory of Production Under Nonstatic Conditions," *ibid.*, pp. 645–667.

cause utilizable capacity remains unused (especially when user cost is low), just as in the case of S_n, and because nonuser cost may consume S_d at a high rate. Institutional constraints (e.g., limitations on shifts) may accentuate the spread between t and T, and adverse institutional conditions may accentuate both user and nonuser costs.[4] Yet ultimately much of the idleness cost resulting is associated with neglect of the dimension or input of time. In the case of S_d, however, unlike in that of S_n, nonuse may give rise to relatively less idleness cost provided that the ratio of user to nonuser cost is relatively high. S_d embodies a roughly given amount of services and they may be extracted sooner or later, whereas S_n is potentially the source of a continuous flow of services, nonuse of which in any period denies that portion of their use forever.

The second subdivision of category (b), human agents, resembles both the first subdivision and category (a). It resembles the first subdivision in that human life is limited in length. It resembles category (a) in that the services of the human agent are perishable; if they are not used, they are lost forever. These services, if not used, are no more storable than the services of category (a) if not used. In contrast, the services embodied in a mineral deposit or a factory building are storable, though subject to varying degrees of attrition or loss in value traceable to nonuse; they flow when the source is worked. Human agents are subject to a high nonuser cost inasmuch as nonperformance of functions reduces capacity to perform, whereas performance of functions increases skill and capacity up to a point. User cost, on the contrary, is relatively low; maintenance of the human organism when active does not greatly exceed maintenance when inactive. In short, the ratio of user to nonuser cost is relatively low, and idleness cost is high when t falls short of T. In a sense, however, as is shown later, the spread between t and T, unless qualified, constitutes an imperfect measure; for the human agent, unlike material agents, may perform not one but a variety of functions and can therefore perform optimally only if the marginal ratios of substitution between types of activity are equal. T and t must, therefore, be appropriately subdivided along functional or activity lines before the cost of idleness or misallocation of time can be assessed.

B. Allocation of Units of Time

In the previous section, time was viewed objectively much as in the history of physics or essentially timeless economic models. Calendar time was employed to measure and compare the potential and the actual rates of flow of services from various sources of services. In this section our concern is the allocation of time among uses; emphasis is placed, therefore, upon subjective time, the time which appears in "our momentary view of the world," in our "percepts" and "memories and expectations."[5] Instants or moments of time as apprehended and comprehended by individuals may not and need not be independent, one of another. Time is not a mathematical abstraction as in physical or economic models which yield timeless solutions. It is, instead, a bridge of transit between a given psychic state and actual or potential successor psychic states.[6]

While allocation of time among uses always takes place in what we may call the present, it is influenced by the manner in which past or future moments condition what is decided upon in the present. Expectations bind the present to the future and the future to the present. Similarly, memory binds the past to the present and the present to the past. "Any point of the calendar axis within most of the supposed lifespan of the individual can by expectation or by memory be brought into relation with each successive station of the moment-in-being."[7] Any moment thus possesses what Jeremy Bentham called "fecundity," or the capacity to affect future moments.[8]

Individual decisions respecting the allocation of time among alternate uses in the present are affected by expectations regarding the future and by memory of the past. It, thus, is affected by prolongation of life which has augmented man's life expectancy and by the decline in fertility in modern times which has increased the relative number of older persons—say persons beyond 60 or 65 years of age—in the population.[9] Given a male expectation of life at birth of 35 years (as was found in many countries 125–150 years ago), 60, 37, and 20 percent of those born attain the ages of 20, 50, and 65. Given a male life expectancy at birth of 50, the corresponding percentages become 76, 59, and 41, and given a life expectancy of 74, they become 97, 93, and 78.[10] Given a life expectancy at birth of 70.2 years, and a gross reproduction rate (GRR) of 2, the fraction of the population aged 60 and over approximates 8.5 percent; but this fraction rises to 22 percent if the GRR declines to 1.[11]

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[4] E.g., see R. C. Blitz, "Capital Longevity and Economic Development," *American Economic Review*, XLVIII (June 1958), pp. 313–329.

[5] Bertrand Russell, *Human Knowledge—Its Scope and Limits* (New York, 1948), pp. 264, 212–217, 274. On man's adaptation to the temporal conditions of his existence, see Paul Fraisse, *Psychologie du temps* (Paris, 1957).

[6] Shackle, *op. cit.*, pp. 16, 20, 23–24. See also Gurvitch, *op. cit.*, pp. 25–33; MacIver, *op cit.*, chaps. 3, 6, 9.

[7] Shackle, *op. cit.*, p. 16; also, Fraisse, *op. cit.*, pp. 83 ff., 151–73.

[8] *An Introduction to the Principles of Morals and Legislation* (1823) (London, 1907), pp. 30–31.

[9] Juanita M. Kreps, ed., *Employment, Income, and Retirement Problems of the Aged* (Durham, 1963), ch. 1.

[10] United Nations, *Methods for Population Projections by Sex and Age* (New York, 1956), p. 76.

[11] United Nations, *The Aging of Population and Its Economic and Social Implications* (New York, 1956), p. 27.

What may be called the store of moments constituting the average man's life, or the life he may yet expect when entering the labor force at age 20 and leaving it at 60 is much longer, therefore, than a century ago; e.g., for males, 50 years or better compared with around 37 to 41 years a century ago, 16 years compared with 12 to 14 years a century ago, and for females at various ages 2 to 4 years more than for males. Moreover, the probability that a person attaining the age of 20 will reach 70, along with friends and associates in his own and neighboring-age cohorts is quite high, 0.55 to 0.75 or higher in modern societies. Accordingly, how the individual allocates moments in the "present," say, in a day or week, may be affected by his memory of many past moments and will be affected by his expectations respecting many future moments. For in a sense all an individual's actual and anticipated moments are woven together into a seamless cloth of experienced and to-be-experienced time which envelops him and conditions his behavior.

For analytical purposes, we may focus upon the allocation of moments of time, or larger units of time, in the "present" and "near future." Actual allocation must be accomplished in an interval so short that the allocative decision, though perhaps reflective of memory and expectation, is not yet subject to change and can therefore be carried out.[12] Even so, the actual allocation will not be independent of the length of the interval to which it relates. For the significance of the alternatives available often varies with the length of this interval. More combinational alternatives become available as the interval is lengthened, and there may emerge something analogous to economies of scale in the use of time. Of course, if the interval is lengthened beyond some point, the influence of memory, expectation, or other variable, may change, undermining ceteris paribus and bringing into being need for a new decision.

What has been said may be put somewhat differently. Actual individual decision respecting the allocation of time among uses must be made in the present. At the same time, though within limits, a better decision can be made if the planning period to which the decision relates is longer rather than shorter. For, almost independently of the influence of memory or expectation, the uses of time in short period 1 (say, day 1 or week 1) are interrelated with corresponding or other uses in subsequent periods of time. Within a short interval, both substitutive and complementary relationships connect various uses of time; yet the relative importance of these relationships in any one interval will vary with the length of the planning period, in part because its elongation produces economies of scale in the use of time and makes possible the introduction of additional uses or more varied combinations of uses.

Consider a short interval, say a week, within which the available uses of time may be assembled by an individual into six categories of essentially homogeneous time. Designate these uses and the time each absorbs *A*, *B*, *C*, *D*, *E*, *F*. If these uses are substitutive and the individual is subject to no constraints, optimum allocation requires that the marginal significance of time put to any one use approximate that put to any other use. If, however, complementary relationships are present, they must be allowed for. Suppose now that the planning period is greatly increased. At least three changes occur: First, the number of uses will rise, say to *A–M*, and the possible combinations will grow. Second, a short interval no longer need be self-sufficient. The devotion of time to any particular use may be shifted from an earlier (later) to a later (earlier) time interval, giving rise to economies of scale in "production" or "consumption." Third, the network of complementarity and substitutability will be modified, probably varying from one interval to the next. A fourth change may also take place. While we have supposed that an allocating individual is free of institutional (and perhaps technological) constraints, this may not be the case. If he is subject to constraints, he may be able to lessen their constrictions if he can plan for a longer period; or the agents responsible for the constraints may relax or intensify them.

It has been assumed that time is to be allocated among six uses, *A–F*, in a short interval. Suppose now that we reduce the six uses to two, *P* and *Q*, embracing *A–C* and *D–F*, respectively. Then the relationships between *P* and *Q* will appear to be substitutive even though complementary relationships had been present and, as we indicate below, even though *P* and *Q* are or may be partially related as complements. This exclusive dichotomy is somewhat misleading, therefore, and it becomes even more misleading when it is applied to longer intervals, for it blankets out the complementary and the substitutive relations which underlie allocation behavior, or at least would underlie it in the absence of serious constraints upon the behaving individual.

In the above discussion it has been implied that the individual dividing time between *P* and *Q*, or allocating it among a larger number of uses, is relatively free of constraints. Actually, such is not likely to be the case. The individual's range of freedom of choice is likely to be quite limited though somewhat free in the neighborhood of the margin of indifference between changes in the *P*/*Q* relationship. The limitations upon his discretion are of two sorts, legal and routinely institutional. His capacity to circumvent the former may be limited except insofar as he can maneuver within the confines of P or Q. A routinely institutional constraint, undergirded more by habit than by extraindividual sanctions, is less binding, in part because it may have been acquiesced in so as to diminish the burden of choosing. Even so, this type of constraint renders choice behavior viscous and may insensitize it to small increments in stimuli.

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[12] E.g., compare Shackle, *op. cit.*, pp. 27–28.

Suppose now that we have a fixed period of time, a day, divisible as before into subperiods of time-use A–F, which are assembled into two periods P and Q, together composing one day. So long as this condition obtains, only a substitute relationship is possible between P and Q; an increase in $P(Q)$ must be at the expense of $Q(P)$, and complementarity is impossible. P and Q cannot be complements unless the day is divided into three time-use subperiods P, Q, and R. Now suppose the day is so divided. Then if use P is a substitute for use Q, an increase in P will be at the expense of Q and possibly also of R; and a decrease in P will result in an increase in Q and possibly R. If, on the contrary, P and Q are complements, an increase in P and hence of Q will be at the expense of R, while a decrease in P and hence in Q will occasion an increase in R. There is a limit, of course, to the extent to which P can be increased if Q remains complementary to P; since R is a finite quantity reducible to zero at most, and perhaps not below some positive fraction of a day.

If the use of time is flexible, it may be possible to allocate a large portion of a given day to a particular use and offset this by allocating little or no time to this use on a subsequent day. Let us divide each day into somewhat variable and shiftable subperiods P, Q, and R, permitting some day-to-day variation in the allocation of time among uses. Then, if subperiod time uses P and Q are complements and use R is postponable, P may be increased on a given day until P and Q together absorb the whole of the day, but on a subsequent day a more or less compensatory decrease must be made in P and Q to permit an increase in R. When such interperiod shifts take place, it is always possible, of course, that the variables governing the preference pattern between P and Q may change and modify the degree of complementarity or substitutability.

C. Work Versus Leisure

It has become customary in the literature on "work" and "leisure" to assume that an objective time period may be exclusively dichotomized into "work" and "nonwork," or "work" and "leisure," or discretionary and nondiscretionary time, and so on.[13] This mode of classification serves certain analytical needs, especially in the short run. But it obscures the processes and considerations involved in the allocation of time, especially over the longer run, and makes for invalid or distorted formulations of time-use problems as well as for multiplication and intensification of the constraints within which bureaucratic administration (corporate, trade union, and governmental) would imprison the individual. The adverse effects of this dichotomization arise not merely from the resultant exclusion of complementary relationships but from other circumstances as well. Thus "work" and "leisure" are heterogeneous categories along with the balance of the day; the smaller time components of the day may be complexly related and subject to considerable variations; optimizing the allocation of time requires giving sufficient weight to the lifespan of the optimizing individual or community; even so simple a division of time as that between "work" and "leisure" reflects the influence of many variables excluded from simple dichotomized models.

Instead of making an individual's demand for "work" or "leisure" depend exclusively upon his income and the price at which he can dispose of his time—i.e., $D=f\ (p_t, y)$ where p_t denotes the price of time and y and D denote income and demand for "work" (or "leisure")—it should be made to depend not only upon these two variables but also upon whatever other variables help to determine the equilibrium between work and leisure. We might write $D=f\ (p_t, y, v)$, *with* D, p_t, and y defined as above, and with v designating all other relevant variables, of which the more important could be broken out of the collection represented by v. Changes therein would modify the preference pattern which usually is taken as given.

Or, we might assume that the individual has a utility function depending solely upon "work" and "leisure"

$$U=g\ (T-W, rW)$$

where U, W, T, and r denote utility, work time, total time, and wage rate, respectively; where, therefore, $T-W$ designates "leisure," and rW income from work; and where therefore the rate of substitution of income for leisure equals the wage rate r.[14] Given this type of model and disregarding such variables as might be included under v above, the amount of time worked per day would vary with the type of wage system in effect,[15] and with the incidence of various taxes and the uses to which they are put.[16] We should not, however, disregard the v variables but introduce them into our equation, since as they change, the marginal rate of substitution between work and leisure may change, as has been suggested. Of the many variables that might be included in v, the multiplicity of consumer goods available, together with several conditions that might intervene, should be considered.

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[13] Many other groupings of time are possible, as has already been suggested. E.g., see Georges Gurvitch, *The Spectrum of Social Time* (Dordrecht-Holland, 1964); also W. E. Moore, *op. cit.*

[14] J. M. Henderson and R. E. Quandt, *Microeconomic Theory* (New York, 1958), p. 23.

[15] E.g., see Herman Wold, *Demand Analysis* (New York, 1953), pp. 130–131; also Kenneth Boulding, *Economic Analysis* (New York, 1955), pp. 800–801.

[16] E.g., see A. R. Prest, *Public Finance in Theory and Practice* (London, 1960), pp. 69–79; T. Scitovsky, *Welfare and Competition* (Chicago, 1951), pp. 90–92; R. A. Musgrave, *The Theory of Public Finance* (New York, 1959), ch. 11.

Suppose that a community subsists upon *one* commodity into which human effort is transformed, and that each family head (or his surrogate) obtains enough of this commodity with 40 hours of labor per week to support his family in comfort. Now suppose that output per hour is doubled by an improvement in method of transformation that entails no increase in inputs besides that under consideration. Then we may reasonably expect each worker to reduce his labor input per week by close to half. He would need to work no longer to earn his support, and he would have little incentive to do more than this, since at best he could expect only more of the one commodity with which he and his family were already nearly surfeited.

This points to the flaw in Say's "Law" when applied in a model involving improvement in the exchange of effort for commodities. It was implicitly assumed that the demand for output was adequate to absorb all of it at competitive prices and would continue to do so as output per man rose in various sectors of the economy. Purchasing power released by an improvement in one sector would swell aggregate demand enough to absorb any amount of labor displaced by improvements in the output of a product for which the price-elasticity of demand was below unity. This argument overlooked the fact that whether displaced labor would be reemployed turned ceteris paribus upon the elasticity of demand for income in terms of effort in various sectors of the economy. The argument would not hold under the conditions laid down in the preceding paragraph. It might or might not hold if only a very small number of noncompeting commodities were produced; for even then demand might be nearly surfeited before the laborsaving improvement was introduced. Indeed, the argument could hold only if a large number of distinct commodities were produced, and if this number increased over time rapidly enough to offset the reduction of labor input per unit of output in particular sectors of an economy. For if uses for purchasing power grow rapidly enough, they will offset any increments therein at the individual and the aggregate level by elevating the demand for income in terms of effort sufficiently to sustain the aggregate demand for labor and the demand of labor for work.[17]

Two polar sets of possibilities are disregarded in what has just been said. At one extreme, men might conceivably work, as some do, primarily for the sake of working, with the result that output is viewed as a mere byproduct of quite secondary importance. In a society completely dominated by Max Weber's "Protestant ethic" all would work for work's sake; the aggregate supply of effort would be independent of the exchange ratio between effort and income and corresponding levels of income. In such a society hard work is a duty, satisfaction in the performance of which constitutes adequate reward. "It is an obligation which the individual is supposed to feel and does feel toward the content of his professional [or occupational] activity, no matter in what it consists."[18] Societies corresponding to this extreme do not, of course, exist. Some societies, however, approximate this extreme more closely than do others, with the result that under otherwise reasonably similar conditions the volume of employment and the output of work tend to be greater in the former than in the latter type.[19] Moreover, in the course of time societies can take on more, or shake off some, of the conduct-determining values included in the category symbolized by the term "Protestant ethic."[20] The esteem in which "work" as such was held certainly increased in later medieval and early modern times. It is quite possible that in recent decades the ethical importance attached to work as such has diminished and is continuing to diminish. That this has happened in the contention at least of publicists.[21] Such is also the implication of Riesman's argument that the inner-directed component of the American population is gradually being swamped by the other-directed.[22]

At the other polar extreme one might locate societies which destroy a large amount of their product. In such societies the need of each and all to meet the requirements of elementary consumption and public destruction would suffice to keep the labor force fully engaged, albeit with little capacity or incentive to progress. While no society quite answers to this description, some have borne a resemblance to it. Somewhat illustrative are the societies engaging in destructive potlatchs as did the comparatively wealthy Kwakiutl Indians living on the northwest coast of America.[23] Somewhat illustrative also are societies which attached great importance to war and periodically destroyed much of their wealth in the pursuit of this objective. Somewhat illustrative too is engagement by the state in pyramid building, that is, in undertakings which (except for possible multiplier and secondary influences) augment the total amount of labor employed but do not add to the aggregate flow of goods and services of the sort for which workers voluntarily exchange effort, at least within limits.[24] A parallel example is the unilateral payment of tribute to a foreign power.[25] Presumably societies also vary over time in respect to the degree they engage in such unproductive or destructive uses of these labor-embodying inputs.

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[17] J. J. Spengler, "Product-Adding Versus Product-Replacing Innovations," *Kyklos*, X (Fasc. 3, 1957), pp. 249–277, esp. pp. 260–267.

[18] Weber, *Protestant Ethic and the Spirit of Capitalism* (London, 1930), p. 54. See also Klara Vontobel, *Das Arbeitsethos des deutschen Protestontismus* (Beru, 1964), pp. 1 ff.

[19] E.g., Germans tend to esteem work more than do Americans. See "The United States and Germany: A Comparative Study of National Character" in D. C. McClelland, *The Roots of Consciousness* (New York, 1964), ch. 5, pp. 78, 82–83, 90.

[20] On the "ethic," see Talcott Parsons, *Structure of Social Action* (New York, 1936), chs. 14–15. On changes over time in relevant values see D. C. McClelland who, while allowing some validity to Weber's "ethic," stresses "the achievement motive," a product of personality characteristics formed in youth. See D. C. McClelland, *The Achieving Society* (New York, 1961), chs. 3, 4, 9.

[21] E.g., see Joseph Wood Krutch, "Can We Survive the Fun Explosion?" Saturday Review, XLVIII (June 16, 1965), pp. 14–16.

[22] David Riesman, et al., *The Lonely Crowd* (New York, 1954), pp. 28–31, 135–166, 184–188.

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[23] E.g., see Ruth Benedict, *Patterns of Culture* (New York, 1946), pp. 178–194.

[24] On pyramid building, see Keynes, *op. cit.*, pp. 128–131.

[25] Compare A. Sauvy's analysis of somewhat similar examples in which additions to the work force do not augment conduct-determining domestic output and expectations. *Théorie génerale de la population,* I (Paris, 1952), pp. 64, 81, 99.

V. The Allocation of Leisure

We have indicated that men have a demand for "work"—i.e., "paid work"—and a demand for "leisure," and we have implied that they have a demand for those relevant time periods which do not fall within the "work" or the "leisure" category. The demand for work is mainly a derived demand; it flows from the fact that the individual requires generalized purchasing power wherewith to acquire want satisfaction, and that this purchasing power is normally gotten in exchange for "work," which is a blanket term for the services flowing from human sources. The demand for "leisure" is not a derived demand in the sense of the demand for work. "Leisure" is usually wanted for itself; it is not mainly or entirely a means, as is "work," but rather an end in itself. Needless to note, the distinction made is subject to the qualification that any means-end distinction, while analytically useful, is substantively inadequate. Valuations reflecting a chooser's culture enter in some degree at every stage of a means-end chain even when clear-cut alternative chains are not available;[1] they thus confer something of the quality of ends upon means, and of means upon ends.

A. The Demand for "Leisure" Versus the Demand for "Work"

The "demand" for work is not entirely a derived demand flowing from the "demand" for generalized purchasing power with which to acquire either a fixed quantity or a steadily expanding quantity of goods and services. If it were entirely a derived demand, then it would be governed by the variety of the goods and services available and the growth of this variety. In some measure, however, "work" is demanded for itself; it yields satisfactions directly, it confers social status, and it provides access to satisfactions realizable mainly or only in the work situation.[2] These several types of satisfaction vary with occupation and profession, however, as Wilensky and others have found;[3] in general, they are greatest when the worker is most fully involved in the set of activities comprising his "work." At the same time, however, the amount of satisfaction associated with particular types of employment is subject to augmentation within limits through changes in the job situation.[4] Similarly, the extent to which the individual's social status depends upon the nature of his employment may increase or decrease somewhat as cultural conditions change.

The "demand" for leisure may be looked upon as a direct demand if one views leisure as a set of activities, services, etc., sought for themselves. This demand will depend, therefore, upon an individual's income, upon his access to whatever elements are essential to his being able to enjoy the forms of leisure he prefers, upon the range of leisuretime activities available, and upon the various social forces making these activities known and attractive. The demand for leisure often resembles a derived demand as well; for indulgence in leisure may operate, within limits, to improve the health and tone of individuals and increase their economic productivity. The demand for leisure may vary in time as may the demand for work, though in general the demand of most individuals for work is a declining one, whereas that for leisure is an increasing one.

As was pointed out earlier, an increase in the demand for work (leisure) must be satisfied at the expense of leisure (work) unless there remains a residuum of time allocated to neither. Let us divide a standard time period D (call it a day or week or month or year) into W, L, and R which denote the fractions of D devoted to work, leisure, and residual activities, respectively. An increase in W entails a diminution in L and/or R; so also with an increase in L, or R, though within limits the demand for R may be too weak to resist the pressure of an upswing in W or L. If D is a short period there is not much scope for manipulating the distribution of D among W, L, and R. If, however, D is a long period, or better still, we envisage a sequence of D's, the division D into W, L, and R may vary from period to period. Then if economies of scale, or other advantages, attend certain patterns of use of W, or L, time for these uses may be made available in larger quantities on some days than on others.

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[1] See Gunnar Myrdal, *Value in Social Theory*, ed. by Paul Streeten (London, 1958), pp. 49, 160, 206–230, and Streeten's comments, pp. xxi–xxv.

[2] See Anderson, *op. cit.*, chs. 3, 7, 11; Friedmann, *op. cit.*, pp. 14 ff, ch. 7.

[3] See above; also R. S. Weiss and D. Riesman, "Some Issues in the Future of Leisure," in E. O. Smegel, ed., *Work and Leisure* (New Haven, 1963).

[4] Conceivably such augmentation might reduce the hours of work needed if it operated to increase output per hour, as did improved living standards in 19th century Europe as well as in present-day underdeveloped countries.

Let us suppose that R has been cut to an irreducible minimum, with the result that we have, as of any day D, a constant amount of time $(D-R)$, to be distributed between W and L in accordance with each individual's preference pattern and his hourly earnings rate and income opportunity. Let us suppose further that his preference pattern changes over time, with L sometimes of greater and sometimes of lesser importance. Then the utility he might derive from $(D-R)$ over a longer period of time would be greater if he could vary his W/L ratio accordingly, though not necessarily in such wise as to change the average ratio for the whole period. He would in effect redistribute W and L among the shorter D periods, a redistribution possible in part because other individuals had different preference patterns over time.

There exist many reasons why such redistributions may be desired; indeed, as was suggested earlier, they are already realized in some measure. One major reason is the economies of scale to be had from the use of leisure time in larger continuous quantities. For example, suppose a worker is employed 5 days at 7 hours a day, or a total of 35 hours; he then has but 2 days a week, the leisure value of the other 5 days being rendered very low by fatigue, journey to work, etc. Now suppose the worker was employed 9 hours a day for 5 days, or 45 hours a week; then every 7 weeks he would accumulate $7(45-35)=70$ hours, or the equivalent of ten 7-hour days which could be devoted to continuous leisure in whatever form the worker desired. The 70 hours would have much higher utility in this form than in daily dabs of 2 hours each on 7×5 days. This type of arrangement would augment the value of L per year without diminishing W; it might even increase the demand for income, should time devoted to periodic vacations entail more expenditure than a similar amount of time consisting in small daily increments. This argument is even stronger in the case of shift work, especially when it entails off-time during portions of the day not easily utilized.

A second major reason for the redistribution of work and leisure time is developing. There is now underfoot a movement to induce workers to retire at 60, and without opportunity, should they so desire, either to return to their old employment or to engage in other activity. This movement could result in the average worker's facing, when retired at 60, 16 to 20 more years of life, disengaged from status-conferring employment and with an income in the neighborhood of half that enjoyed in the last decade of his work life—unless the state supplemented his income enough to bring it up to the average disposable for his occupational group. If on the contrary, all able-bodied persons aged 60 to 69 were allowed to work at least until they attained 70, they would have accumulated more savings and the expected years they would need support in retirement would have become not 16 to 20, but 10 to 13. What in effect the older worker requires, therefore, given *ex hypothesi* a fixed work fund, is the opportunity to exchange leisure for work with his younger associates under a system that in effect transfers leisure from a man's older to his younger working years and work from his younger to his older working years. By this intertemporal transfer the utility of the older person's aggregate is augmented through better intertemporal allocation.

The hypothesis that the amount of work is fixed and needs to be distributed is not, of course, tenable, though it seems to underlie various bills introduced into the Congress for the purpose of imposing statutory limitation upon the workweek.[5] The aggregate amount of employment as of unemployment tends to vary seasonally and otherwise within limits. Employment may be held down, of course, by a so-called dearth of aggregate demand, by personal and/or locational shortcomings of individual workers, by arrangements that fix the total price (i.e., wage or salary and other employment costs) of labor above its value in marginal revenue terms, and even by suboptimal programing of diverse activities. Reduction of unemployment can be accomplished only through removal of its specific causes, among which relatively low productivity/employment-cost ratios may prove quite significant. Action based on the assumption that the amount of work is fixed amounts to employment-reducing action based on mirage.

Individual response to increase in the demand for leisure is not free of constraints. A decrease as well as an increase in the number of hours worked per day, or a change in the work pattern, is generally the result of bargaining and arriving at contractual agreements which may lag behind the growth of the effective demand of some workers for additional leisure. Yet even though these changes lag behind changes in the preferences of some workers they will precede those of other workers who would like to continue to work longer hours; for it is seldom possible to permit different components of a company's labor force to be employed workdays or workweeks of different length. The variability permissible in the age of "Mom and Pop" stores has been given up for the supposedly greater efficiency of bureaucratically regulated larger-scale enterprises. One outcome is that workers in industries marked by relatively low hourly rates are unable, or not often able, to augment their weekly pay by working longer hours even when they prefer to do so; their main recourse is moonlighting.[6]

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[5] E.g., M. R. Northrup's testimony in *Hours of Work, Hearings, op. cit.*, pp. 553–619; also the testimony of M. W. Reder, *ibid.*, pp. 724–726. See also C. E. Dankert, "Automation, Unemployment, and Shorter Hours" in Dankert et al., *op. cit.* (New York, 1965), ch. 10.

We have touched only upon factors which affect the demand for "work" and the demand for "leisure." These factors determine the individual's indifference map in respect to "leisure" and "work" viewed as a substitute for income. Then the actual work-leisure combination chosen in the individual case is determined by the rate of earning per time period and the various incomes accessible, subject to the incidence of outside income and legal and other constraints on the number of hours of work which the individual is free to perform.

B. Other Factors in the Work-Leisure Choice

Let us turn to other conditions which bear upon the preference pattern of the individual and thus determine what is for him the optimum rate of exchange between "work" and "leisure," given his hourly earning rate and income possibilities. This pattern reflects the set of variables that were earlier assembled under v, and changes as they do. It is necessary, of course, that the individual have a clear-cut notion of "work" and "leisure"; otherwise, the two will not be distinguished, being intermixed and governed as they once were in the West by tradition and the seasons, and eventually, in some measure, by emerging bureaucracies.

The meaning of "time" and the role of "work" have continually changed, along with the intra- and extra-individual determinants of the individual's supply of effort.[7] In primitive and preindustrial societies, leisure and work were not usually sharply differentiated and time was seldom thought of as "scarce."[8] But these conditions changed and it was not until the late 19th century that the problem of leisure commanded widespread attention in the West; the Industrial Revolution had accentuated demands upon the worker's time and undermined the tradition that man should work only 8 hours and recreate 8 hours.[9] In sum, insofar as the individual is free to choose, how he divides his time between "work" and "leisure" (or nonwork) will turn not only on his rate of earnings and his income level but also on v and changes therein which affect the comparative attractiveness of "work" and "nonwork" as actually practiced, together with the time horizon to which his choice is related.

The individual is seldom entirely free to exercise his choice between work and leisure either for short periods or for that portion of his lifetime—say 80 percent of the 50 to 56 years to which he may look forward on his 20th birthday—in respect to which he would like to choose. In keeping with a suggestion of E. Blakelock,[10] we may conceive of man's time as a budget of blocks which, though not storable, otherwise resemble a budget of money in being liquidable and exchangeable for other values, among them the elements attainable through "work" and "leisure." Time is *flexible* insofar as the individual is free to organize his time-absorbing activities, or uses of liquid time, as he chooses, carrying on some in the present time period and some in later time periods, always with the object in view of attaining a maximum flow of satisfaction from the stream of time at his disposal.

Time, of course, is not entirely flexible; much of it is *rigid* in that certain activities can be carried on only at certain times and in more or less prescribed measure because of constraints imposed either by the external physical environment or by man-made arrangements. The relative amount describable as rigid is increasing; though man is freer of his natural environment than formerly, his activities have become increasingly subject to controls emanating from an increasingly bureaucratized state, industry, and trade union apparatus. Even a great deal—perhaps an increasing amount—of his flexible time is becoming quasi-rigid in that the use of so-called leisure time is becoming increasingly routinized and institutionalized or fenced in by lack of easy access to space or other essential complements to leisure time. Indeed, response to leisure resembles response to what Friedman calls permanent and as yet nonpermanent income; that portion of leisure long enjoyed tends to become ordered by habitual and institutional guides, whereas new increments of leisure remain uncommitted for a while, but not necessarily permanently. Accordingly, while economic development enlarges man's range of choice, it may also circumscribe it. Of course, technological or other changes can produce profound changes in the patterns of consumption of families and hence in their patterns of leisure use, but these in turn tend to become routinized. Because of these tendencies to the routinization of the use of time and income, neither time nor income remains as discretionary as is sometimes supposed; both get committed.

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[6] On moonlighting, see P. E. Mott, "Hours of Work and Moonlighting," in Dankert et al., eds., *op. cit.*, ch. 5.

[7] E.g., see Adriano Tilgher, *Work, What It Has Meant to Man Through the Ages* (New York, 1930); G. Gurvitch, *The Spectrum of Social Time;* Walter Firey, "Conditions for the Realization of Values Remote in Time," in E. A. Tiryakian, ed., *Sociological Theory, Values, and Cultural Change* (Glencoe, 1963), pp. 147–60; R. V. Presthus, "The Sociology of Economic Development," *International Journal of Comparative Sociology*, I, September 1960, pp. 199 ff; M. J. Herskovits, *Economic Anthropology* (New York, 1952), pp. 91–99, 109–23, 395–415.

[8] W. E. Moore, *op. cit.*; Nels Anderson, *Dimensions of Work* (New York, 1964), pp. 94–98, 102, 110–114; R. V. Presthus, "Weberian versus Welfare Bureaucracy in Traditional Society," *Administrative Science Quarterly*, VI, June 1961, pp. 14–24; Friedmann, *op. cit.*, chs. 6–7; Margaret Mead, ed., *Cultural Patterns and Technical Change* (New York, 1955), pp. 35, 70, 136, 141, 160, 164–165, 170–171, 174–175, 236–39, 244.

[9] G. Langenfelt, *The Historic Origin of the 8-Hour Day* (Stockholm, 1954); S. de Grazia, *Of Time, Work, and Leisure* (New York, 1962).

[10] "A New Look at Leisure," *Administrative Science Quarterly*, IV, March 1960, p. 51 ff.

These rigidities probably tend to reduce the amount of time a man works in the present and they certainly tend to reduce how much he works (relative to how much he could work) in a lifetime; they thus give rise to enforced "leisure" which yields less utility than does freely chosen leisure. The rigidities directly reduce how much a man may work since, barring the limited opportunity to moonlight, most men are free to work only as long as their employers will engage them; they may also reduce worktime indirectly since, if work is viewed as a means to leisure and circumscription reduces the utility of leisure, especially at the margin, the disposition to work will be less strong insofar as it is animated by the need for money to enjoy leisure.

The uses to which time is put today may affect the uses to which it is put tomorrow.[11] For example, as was suggested earlier, technological change, by increasing average income, tends to reduce the time devoted to work thereafter unless enough new wants are generated; [12] or the state and other collectivities augment the demand for such goods and services as are relatively nonamenable to supply and sale by unassisted private enterprise. Again if, as some now fear, only academic excellence is stressed in the educational system to the exclusion of other forms of excellence which seem to be better adapted to developing new wants and creating employment, the aggregate demand for work will not keep pace with the supply of hours that might be so used.[13] In sum, the uses made of time today tend to affect the content of v and attitudes toward work and leisure, together with tomorrow's income levels and time rates of earning.

As has been noted, time devoted to leisure may be both a substitute for, and a complement to, time devoted to work. This tends to be overlooked because, as was pointed out earlier, complementarity can exist only if it is the only relation, or if time is put to three or more uses. Presumably, the dominant relationship, at least until recently, was substitutive. The decline in the number of hours worked per time period is traceable in considerable measure to the rise in average income. A 1-percent rise in income per standard workweek resulted in an 0.27 decline in hours worked in the United States in 1890–1950, an 0.34 decline in Canada in 1921–41, an 0.39 decline in Great Britain in 1911–51, and an 0.92 fall in Germany in 1895–1950.[14] "Decreases in hours were not systematically associated with increases in income, at least in the short run;" depression and war played a part, with rising incomes creating a "conducive social, political, and economic atmosphere." [15] The decline in hours took the form of reduced hours per week, and not that of diminution in labor-force participation except among Negroes and foreign born. Weekly hours of labor force participation per 1,000 males 14 and over declined 41 percent in the United States in 1890–1950, 27 percent in Britain in 1911–51, 28.7 percent in Germany in 1895–1950, and 17.5 percent in Canada in 1911–41. Corresponding declines among females were 4, 14, and 7 percent in the United States, Britain, and Germany; only in Canada was a small increase recorded in 1911–51. Reduction in hours supposedly was preferred to reduction in labor-force participation, on the ground that it better satisfied the composition of the aggregate demand for leisure.[16]

Presumably, the so-called "imitative consumption" or "demonstration" effect could have some bearing upon the reaction of the length of the workweek to rising hourly rates. Given the ubiquitousness in the United States of the many forces generating the "demonstration effect" and the subjective standards of living according to which individuals would like to live, these standards probably vary much less from one occupational group to another than do its hourly earnings and the objective standards of living according to which its members actually live. One might expect, therefore, that the ratio of the percentage decline in the standard workweek to the percentage increase in hourly earnings would be lower in low-income than in high-income occupations. Other factors, however, among them difficulties attendant upon a firm's working different groups different hours and upon different firms pursuing different policies, could prevent the manifestation of such inverse relationship between level of earning and response of length of workweek to increase in earnings; [17] indeed, the smallness of interindustry variance in the normal workweek suggests that these factors are quite powerful.

An increase in hourly income tends to be accompanied by an increase in the demand for leisure, in part because consumption takes time and more consumption takes more time, acting as a tax on time to be added to the time cost of acquiring the goods consumed. Conceivably, if the rate of consumption continued to increase, it might eventually absorb all the time that could be devoted to it, thus setting a limit to individual personal consumption. **An increase in leisure tends** to be accompanied by an increase in the demand for income, since the use of time in the form of leisure usually costs money. Normally, causation runs from increase in income to increase in leisure, since the increase in income usually is the result of heightened hourly earnings and hence permits a release of time for "leisure." Taste for leisure could, of course, be intensified in the absence of an increase in hourly earnings, with the result that some nonwork time would be diverted to both "leisure" and "work."

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[11] No reference is made here to quite short-run sequences, such as tendency of absenteeism to be low in periods after strikes when workers are short of money. E.g., see Neil J. Smelser, *The Sociology of Economic Life* (New York, 1963), p. 49.

[12] Spengler, "Product-Adding Versus Product-Replacing Innovations," *loc. cit.*

[13] On the undesirability of the present exaggerated emphasis upon academic excellence, see McClelland, *The Roots of Consciousness*, pp. 46–61. See also McClelland, *The Achieving Society*, p. 388, where he observes that "if man wants to control his destiny, he must learn to deal less in terms of the supposed reasonable consequences of historical events and more in terms of their often unintended or indirect effects on the motives and values of the next generation."

[14] Clarence D. Long, *The Labor Force Under Changing Income and Employment* (Princeton, 1958), pp. 272–73.

[15] *Ibid.*, p. 271.

[16] *Ibid.*, pp. 274–81.

[17] For a ranking of occupations by annual earnings, see M. A. Rutzick, "A Ranking of U.S. Occupations by Earnings," *Monthly Labor Review*, LXXXVIII, March 1965, pp. 249–255. The variance is greater than that found in weekly hours worked.

A substitutive relation obtains between "paid work" and the "unpaid work" components of the nonwork portion of the day, which includes "leisure" time and all other time not devoted to "paid" work. The male worker may do more hours of "paid" work and use the proceeds to hire services that could be supplied by and within the household economy; or he may do less "paid" work and perform these household-oriented and similar services himself. His tendency to pursue the former course will vary positively with the ratio of his paid-work earnings rate to the cost of having the services performed; if, after correction for the fact that income from "paid work" is taxed, the ratio is close to unity or falls below it, it will probably pay a worker to perform the services himself. The female worker, especially the married female worker, is confronted by a similar choice. In general, with hourly earnings given, whatever raises (lowers) the cost of services connected with the household tends to decrease (increase) the hours devoted to paid work.[18] French studies indicate that employed married women devote less time to sleep and household activities than do nonemployed married women.[19]

Interrelations among components of the labor force may indirectly affect the incidence of "nonwork" upon the aggregate amount of unemployment. Even though interfactor relations should be predominantly substitutive over the longer run, they could often be complementary in the shorter run. The level of employment in a population depends significantly upon the relative number of administrative and related personnel in the labor force. Let us call these A and the balance of the labor force B; then within limits the fraction $E/(A+B)$ of the total labor force $(A+B)$ that is employed depends upon the ratio A/B, tending to rise and fall therewith. Insofar, therefore, as enforced leisure or other circumstances tend to reduce the supply of A time and thus to depress the aggregate demand for B, the unemployed fraction of the labor force will be higher than it otherwise would have been.

Up to this point emphasis has been placed upon the economic aspects of the work-leisure relationship. It has been noted that the marginal rate of substitution between paid work and leisure, income and hourly earnings rates being given, is conditioned by a set of variables labeled v and affected by the residuum of time per period, say, per day, not explicitly included under "paid work" time or "leisure" time. It has been implied also that the elasticity of demand for income in terms of effort[20] turns on how the decisionmaking unit is defined: Is it the household, as the sociologist emphasizes, or is it each potentially earning member of the household, or is it the working members of the household, or is it the working members of the household viewed as joint suppliers? Purely sociological considerations have been neglected, however, except insofar as they have been recognized as elements in v. Presumably these considerations become more and more important as the "discretionary" fraction of an individual's disposable income decreases.

An economy embraces many units—households, universities, churches, business firms, units of government, and other collectivities which have the capacity for "action in concert"—all of which participate not only in the economy but also in other systems composing the society as a whole.[21] Kinship groupings constitute an important exemplar of these collectivities; they affect the nature and degree of labor-force participation which may change as the kinship groupings change and they condition the work role of females and the aged.[22] In general, the sociologist maintains, many more variables than wages or salary alone determine changes in the amount of work offered by an individual.[23] These account for various "facts" of the market,[24] among them the accent on security found in the labor market.[25] They suggest that noneconomic as well as economic circumstances surrounding work and leisure, respectively, will condition work-leisure equilibria and the extent to which work and/or leisure absorb residual time not included in either category. They help explain occupational and professional differences in attitudes toward work and leisure noted elsewhere in this paper.

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[18] On the relations between leisure, work at home, and work in the market, see Jacob Mincer, "Labor Force Participation of Married Women," in H. Gregg Lewis, ed., *Aspects of Labor Economics* (Princeton, 1962), pp. 26–68; Long, *op. cit.*, 123–32, 276.

[19] Alain Girard, "Le budget-temps de la femme mariée dans les agglomerations urbaines," *Population*, XIII, October–December 1958, pp. 591–618; Girard and Henri Bostide, "Le budget-temps de la femme mariée à la campagne," *ibid.*, XIV, April–June 1959, pp. 252–282.

[20] Lionel Robbins, "On the Elasticity of Demand for Income in Terms of Effort," *Economica*, X, June 1930, pp. 123–139; Paul H. Douglas, *The Theory of Wages* (New York, 1934), pp. 295–302; J. R. Hicks, *The Theory of Wages* (London, 1963), ch. 5, and *Value and Capital* (Oxford, 1948), pp. 36–37; Long, *op. cit.*, pp. 120–133, 268, 276; H. G. Vatter, "On the Folklore of the Backward Sloping Supply Curve," *Industrial and Labor Relations Review*, XIV (July 1961), pp. 575–586.

[21] Talcott Parsons and Neil J. Smelser, *Economy and Society* (Glencoe, 1956), pp. 14–16, 85 ff.; 114 ff.; 156–57.

[22] *Ibid.*, pp. 53–56, 88–91, 147–51; Smelser, *op. cit.*, pp. 60–61, 108, 110–111.

[23] *Ibid.*, p. 74, also pp. 75–79, 88–92. See also F. Friedlander and E. Walton, "Positive and Negative Motivations Toward Work," *Administrative Science Quarterly*, IX, September 1964, pp. 194–207; C. R. Noyes, *Economic Man*, I (New York, 1948), pp. 549–589.

[24] Parsons and Smelser. *op. cit.*, p. 156

[25] Smelser, *op. cit.*, p. 88.

As has been shown earlier, sociological as well as economic factors define the work-leisure problem confronting the older workers. The economic problem is relatively simple; the income of the older worker declines greatly when he retires, especially when he retires prematurely, and his relative position thereafter deteriorates under the double impact of inflation and his nonparticipation in the fruits of economic progress.[26] The noneconomic problem is more complicated; the older worker is abruptly disengaged, especially when he is retired forcibly and prematurely, from forms of participation upon which his social status depends and from activities which sustain his self-image. This disengagement is especially painful in the modern Western World where the kinship system has isolated the aged, especially the unemployed aged, and deprived them of individual identity and significant membership in the kinship system.[27]

C. Optimizing the Distribution of Work and Leisure Overtime

We may conceive of the male as normally entering the labor force around his twentieth year and remaining therein until in his sixties or early seventies. Let us fix the terminal years at 20 and 70 for both male and female, while recognizing that a smaller fraction of the female population of working age will enter the labor force and that its participation may be temporarily interrupted by familial obligations. Then, of each 100 white males who enter the labor force at 20, about 80 will be living at 60, about 56 at 70; the corresponding figures for white females are close to 90 and 75. Each individual of 20 thus is confronted with the expectation of a stream of time of perhaps as much as 50 years in the course of that portion of his expected life during which he is thought of as in the working-age category. When he reaches 60 he can look forward to about 16 more years of life if he is a white male, and about 20 more for a white female; at 70 these expectancies become about 10 and 13 years.

Each individual faces the problem of maximizing the utility he may draw from the stream of time available to him while he is in the working age category and thereafter. Let us fix the work-life span at 50 years on the supposition that mortality is zero within the 20 to 70 working-age bracket, and let us disregard the post-70 portion of the time stream for the present. Each individual wants to convert this stream of time into the greatest possible stream of utility. Such conversion depends upon many circumstances. Here, however, our concern is with three uses of time, "work," "leisure," "residual activity"—*W*, *L*, and *R*. Because of changes in man's preferences and the circumstances confronting him, it is impossible to lay down a 50-year plan, even on the supposition of zero mortality within the 20 to 70 age bracket. The best he can do is to redistribute his time optimally between *W*, *L*, and *R* for decision periods of sufficient duration to permit his achieving economies of scale from his several uses of time, especially *W* and *L*. A day or a week is too short for this purpose, and more than a year would be too long, since the individual would be giving up freedom of choice for a longer interval than was necessary. He minimizes the temporal side costs (journey to work, etc.) of actual paid worktime by reducing the ratio of this nonpaid work time to that part of worktime which is paid for. Thus, if he worked 45 instead of 35 hours per 5-day week and received the time thus saved as leisure time, his side costs would be only about seven-ninths as great. He could accumulate 10 days off, a most attractive block of time, every 7 weeks, since in that interval he would have worked 315 (i.e., 7×45) hours, or the same amount as 9 weeks at 35 hours per week would amount to. The 2 weeks (including 10 workdays) made available by this arrangement would be worth a great deal more than the alternative; namely, 70 hours in the form of thirty-five 2-hour periods.

Because of institutional constraints, it might not be possible to *optimize* fully the distribution of time between work and nonwork. Approximate optimization is possible, however. It consists in firms granting *all* full-time workers periodic vacations which approximate in aggregate hours the accumulation of hours resulting from redistribution of time between work and nonwork. Under arrangements of this sort the utility derivable from the individual stream of time would be considerably augmented. Current arrangements while they provided 155 more hours of leisure in 1960 than in 1940, and, as reported earlier, far more nonwork time than formerly, still are quite suboptimal since they provide too large a fraction of this leisure in small doses.[28]

As the problem of optimizing leisure comes to be appreciated by industry and trade-union leaders, it is to be expected that the number of workweeks per year will be reduced. Conceivably, by the end of this century the number of workweeks per year could be down in the 40 to 46 range. Reducing the workweek may, of course, produce a partially countervailing response. Increase in the length of periods of leisure may increase the expenditure per period so much that more work will need to be done to permit the purchase of the goods and services complementary to leisure. Henry

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[26] Kreps, ed., *op. cit.*

[27] Smelser, *op. cit.*, p. 61; Friedman, *op. cit.*, pp. 125–135.

[28] Henle, "Recent Growth of Paid Leisure," *op. cit.*, pp. 249–257, esp. p. 256.

Ford's prescient observation will have become fully corroborated.[29]

Were the older worker free to attempt to distribute his time optimally between work and nonwork, he would not present a special problem. But this is not the case. As has been noted, he is often subjected to pressure to retire in the sixties even though his doing so will greatly reduce his current and prospective income and undermine his social status which usually is closely identified with his occupational status. Let us therefore look at the problem of optimizing the utility derivable from the stream of time identified with the interval of life lying between age 20 and 70.

The temporal distribution of a worker's lifetime quota of hours of work has become a major problem mainly because workers in and beyond the sixties are being increasingly subjected to constraints upon their use of time. So long as each individual is quite free to distribute his time as he sees fit between work and leisure, there is no problem; then his *ex-post* experience tends to confirm his *ex-ante* anticipations, since any disparity tends to evoke a corrective response. The condition of most individuals under 60 probably approximates that of such a supposedly quite free individual, subject, of course, to the industrial constraints discussed. But this freedom is not the lot of all individuals above 60; their right to work is constrained and they may be compelled to consume more leisure than they prefer. Hence their work-leisure relationship often tends to be suboptimal, whereas that of persons under 60 tends to be more nearly optimal. This suboptimality may be reduced in two ways: (a) It can be greatly reduced by removing all collective constraints on the employment of persons over 60; or (b) it can be appreciably diminished, at least in theory, by distributing leisure more optimally over an individual's adult lifetime.

Let us illustrate (b). Suppose that collective constraints exist, having been imposed by freedom-reducing collectivities (e.g., the State, trade unions, employer associations, insurance combines). Suppose that a representative male enters the labor force at age 20 and remains in good health until his upper seventies. In the United States, with 1955 mortality, about 54 percent of those reaching 20 attained 70, and by the year 2000 this percentage may approximate or even exceed 75. Our representative individual, if he be free to do so, may choose to work 40 hours per week 48 weeks per year; he then will work 1,920 hours annually and 96,000 hours over a 50-year period. Suppose now that he is compelled to retire at age 60; then he would work only 76,800 hours in the course of his lifetime. Given such restriction, however, he might prefer a distributional pattern other than that allowing 1,920 hours per year for the years 20 to 60 and zero hours for the years 60 to 70. For example, he might prefer to spread the stipulated 76,800 hours over the 50-year interval, age 20 to 70, and work (say) 32 hours per week 48 weeks per year, or 35 hours per week 44 weeks per year. He would prefer this arrangement ceteris paribus so long as his experiencing 72 hours of leisure per week beyond age 60 reduced its marginal utility below the level associated with his experiencing 40 hours of leisure per week as he would when working 32 hours weekly over a 50-year period.

It does not follow, however, that a representative worker aged 20 will be disposed to elect some such seemingly preferable arrangement. For various reasons he may be reluctant to do so; ceteris paribus conditions do not hold. He would have to allow for the probability that his survival to age 70 is less than unity, and that his subjective uncertainty may further reduce the probability coefficient which he employs. He would have to allow for the fact that he might have become disabled by age 60. He would also have to allow for the possibility that by the time he had reached the age of 60, either his cumulated "right to work" beyond 60 might be denied, or that, irrespective of workers' past work records, individuals over 60 would no longer be excluded from the labor force, more intelligent or flexible conditions of employment having come into effect. He would have to allow further for two partially offsetting conditions: (a) That income foregone prior to his reaching age 60 could not be saved and thus enabled to earn cumulating interest and finally become available after age 60 as interest or annuity "income"; (b) that given (say) a 2-percent-per-year increase in pay per man-hour, average hourly wages are higher when one can work in his sixties than when one must retire at 60. Under likely circumstances, the gain under (b) would outweigh the loss described under (a). Our representative worker might also want to allow for the possibility that complements to leisure might have become easily available by the time he had attained age 60, thereby diminishing notably the disadvantage of being without regular employment in the sixties.

Even though swapping work in his early years for the guarantee of work in his post-60 years may lack appeal to young members of the labor force, a modified form of such swapping is indicated. At present, adjustment of available employment to decline in the demand for any specific kind of labor tends to be discriminatory; resulting unemployment is heavily incident upon relatively young workers (who lack seniority) and upon older workers who are "persuaded" to retire. The displaced younger workers tend to be reemployed when demand rises, or to find work elsewhere; the forcibly retired older workers are virtually condemned to a life of involuntary leisure. Under these circumstances it is preferable that adjustment to a decline in employment be accomplished through a commensurate temporary reduction in the length of the workweek. (We are ignoring for the moment the arguments that most unemployment—of older as well as of younger workers—arises from deterrents to profitable investment and from making the cost of labor too high in light of its productivity; the issues raised, though highly pertinent to the employment of older workers, are of a different order than the one under discussion.) Postulate a given industry comprising 1,000 persons who normally average 1,920 hours per year, or 1,920,000 hours in the aggregate. If demand for these labor inputs declines 10 percent, each worker's allotment of hours may be cut 10 percent, or 100 of the workers may be laid off. The latter alternative is likely to add some older workers to the permanently unemployed and to render difficult the reemployment of some of the discharged younger workers. The former alternative avoids these outcomes and provides a better basis for the lengthening of the workweek as demand rises; it does not make more difficult, should demand not rise, the transfer of excess workers (preferably younger ones) to expanding sectors. The first alternative, in short, is flexible, essentially nondiscriminatory, and hence calculated to improve the temporal distribution of both work and voluntary leisure.

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[29] "There is a profound difference between leisure and idleness. We think that, given the chance people will become more and more expert in the effective use of leisure . . . But it is the influence of leisure on consumption which makes the short day and the short week so necessary." So observed Henry Ford in an interview reported in the *Monthly Labor Review*, 23 (December 1926), pp. 1162–1165, and *ibid.*, 85 (March 1962), p. 257.

If we would optimize welfare we must assert the older worker's "right to work," since freedom to exercise such right is essential to the maximization of individual welfare, and since there exists no insurmountable economic organizational barrier to the older worker's realizing this right, the constraints having been manmade. Actualization of this right is quite important also, given the present inadequacy of most retirement incomes, especially those received by individuals retired at 60, to supply the families of retirees with the necessities and conveniences of life, together with the fact that compulsory retirement at 60 reduces a male cohort's man-years of work (and hence output) by 10 to 15 or more percent. This right is more readily actualized by temporarily reducing hours in times of unemployment than by laying off some workers (especially older ones) completely, in order to reduce the size of the labor force.

D. Emergence of Work-Leisure Decisions

In the foregoing discussion, attention has been focused upon aspects of leisure as manifested in modern societies, especially the American. It may be well, if only to supply perspective, to conclude the analysis with a brief look at the question of the emergence of time allocation as a problem, and to note certain intercountry differences in work-leisure patterns.

Time allocation varies with the stage of development of economies, and problems of concern in the present study are associated mainly with a high stage of economic development. Labor force participation is lower in advanced than in underdeveloped countries, given adjustment for differences in age structure, though the difference in actual input of labor may be reduced by differences in the number of hours worked per year. Average activity rates for males, standardized for age structure, approximate 60.5, 62.8, and 65.1 per 100 males, respectively, in industrialized, semiindustrialized, and agricultural countries; they range from close to 50 to over 70. Corresponding female rates, though not quite as accurately reported as male rates, are higher in industrial than in agricultural countries; the major differences are found among those below 15 and over 59, especially over 64. Of each 100 males 65 and over, only 37.7 are economically active in industrialized countries; the corresponding rates for semiindustrialized and agricultural countries, 61 and 70.1, are high in part because a somewhat smaller fraction of those 65 and over may be over 70. The corresponding rates for females 65 and over in industrialized countries is 7.1, and in agricultural countries, 14.3. For males 65 and over by country, the rate ranges from close to 20 to about 80, and for females 65 and over, from close to 5 to nearly 60.[30]

Males in industrialized countries spend a smaller fraction of their post-age-15 years in the labor force than do those in semiindustrialized and agricultural countries. At age 15 the male in an industrialized country may expect 54.5 years of life, of which only 45.3, or 83.1 percent, will be in the labor force. The corresponding rates for semiindustrial countries are 49.5 and 43.1 (i.e., 87.1 percent); for agricultural countries, 46.1 and 41.5 (i.e., 90 percent). The intercountry range is very great; in the United States, the corresponding figures are 53.4 and 41.5 (i.e., 77.7 percent), and in British Honduras, 42.7 and 40 (i.e., 93.7 percent).[31]

Because of intercountry variation in hours worked per year, the data presented in the two preceding paragraphs provide an incomplete picture of the fraction of the potential supply of hours that are devoted to work, leisure, or residual activities. When capital and/or land is in short supply, the number of hours worked per year is likely to be less than would have been worked had these complementary factors been available in larger amounts. Furthermore, if work cannot be programed with sufficient skill, and employment is subject to great seasonal variation, the average number of hours worked per year will fall quite short of the 2,000 to 2,500 hours composing a work-year of 50 weeks of 40 to 50 hours per week. There may be potentially available in an economy a great many more hours of work, especially for nonagricultural undertakings, than are being used, though perhaps not as many as has sometimes been suggested.[32]

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[30] United Nations, *Demographic Aspects of Manpower*, Population Studies, No. 33 (New York, 1962), pp. 12, 14, 20, 22, 58–63.

[31] *Ibid.*, pp. 20, 71–72.

It often is easy to move from the observation that the number of hours worked per year is quite low in a society relying for support almost entirely on subsistence agriculture to the conclusion that leisure is preferred to work.[33] This conclusion is misleading. It may be that the productivity at the margin of additional hours devoted to small plots of land is close to zero, though not infrequently work is carried on under such conditions that its yield is little above zero;[34] or there may be little access to products other than subsistence for which time in the form of work can be exchanged.[35] Given access to products, or to work which can be exchanged for products, the demand for "work" shifts rightward.[36] Work can become so institutionalized in an essentially traditional society that there, much as in a modern society, the amount of time devoted to leisure can be increased only by increasing output per man-hour of work.[37] It is evident that as a society progresses and output per worker rises, the significance of work as a means to goods and services rises and leisure takes on a sharper and more explicit meaning. As a result there comes into being a kind of work-leisure choice situation to which the individual responds, although he is subject, of course, to certain constraints.

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[32] E.g., see Colin Clark and Margaret Haswell, *The Economics of Subsistence Agriculture* (London, 1964), pp 113–114, 121–123, 126, 128, 131, 135–148; T. W. Schultz, *Transforming Traditional Agriculture* (New Haven, 1964), ch. 4.

[33] *Ibid.*, p. 26; M. J. Herskovits, *Economic Anthropology*, 2d ed. (New York, 1952), pp. 88–91, 117–123.

[34] Clark and Haswell, *op. cit.*, ch. 5, esp. pp. 88–94.

[35] Some estimates of hours worked per year are given in *ibid.*, ch. 5, 7; Herskovits, *op. cit.*, pp. 91–99, 106–107; C. J. Erasmus, "Work Patterns in a Maya Village," *American Anthropologist*, LVII, No. 2, part 1 (April 1955), pp. 323–333; W. D. Hopper," "Seasonal Labor in Cycles in an Eastern Uttar Pradesh Village," *Eastern Anthropologist*, XVIII, Nos. 3–4 (August 1955), pp. 141–150.

[36] E.g., R. M. Prothero, "Migratory Labor from North-Western Nigeria," *Africa*, XXVII (July 1957), pp. 251–261; Marvin Harris, "Labor Emigration among the Mocambique Thonga: Cultural and Political Factors," *ibid.*, XXIX (January 1959), pp. 50–66; K. N. Sharma, "Occupational Mobility of Castes in a North Indian Village," *Southeastern Journal of Anthropology*, XVII (summer 1961), pp. 146–164.

[37] Sol Tax, *Penny Capitalism: A Guatemalan Indian Economy*, Smithsonian Institution, Institute of Social Anthropology, pub. no. 16 (Washington, 1953), pp. 85–107, esp. pp. 94–95.

APPENDIX

Some Recent Views of Leisure

The growth of leisure is as characteristic of our times, according to Paul F. Douglass, and "... as representative of our modern spirit as the Parthenon was an expression of the age of Athens and the Amiens Cathedral a symbol of the Gothic concept of 13th century christianity." Describing the basis of this new leisure, the author notes that the contemporary mode has evolved from a feudal agricultural society, thence to the industrial era which brought the strenuous factory system, into "a creative and livable era characterized by freely disposable time and the wherewithal to enjoyment."[1]

For the most part, authors who have recently turned their attention to the question of leisure have stressed the major point made by Douglass, i.e., that improving technology was rapidly making possible both increased output and reduced working time. Attempts have been made to measure the worth of this increase in nonworking time by assuming that alternatively it could have been spent in the production of goods. In this way it is possible to estimate net national product and the rate of economic growth when the assumed value of leisure is included. The much higher national product figures which emerge from these calculations provide a somewhat broader perspective within which the longrun effects of technological change can be appraised.

This "opportunity cost" estimate of the value of leisure is a valid measure, however, only insofar as (1) greater leisure has actually been chosen at the expense of greater output and income; and (2) the distribution of leisure over the labor force (and for each member through his lifespan) is at least roughly in accord with worker preference. Wilensky's study, discussed below, indicates that in fact that portion of leisure which accrues during working life is quite unevenly apportioned among occupational groups. In addition, many protests have been voiced against the growing practice of bunching leisure in the form of longer retirement periods.

The question of whether increases in nonworking time have been chosen in preference to increased incomes, or whether the amount of leisure has grown primarily as a result of attempts to spread the work, has until recently received surprisingly little analysis. The apparent assumption of most writers is that the tradition of pursuing simultaneously the twin goals of leisure and income reflected workers' actual preference during the 19th and roughly the first third of the 20th century. But the maximum hour legislation of 1938 and the retirement provisions of the Social Security Act of 1935 have been explained in part by the need to increase the total number of jobs, and to allocate them to younger and middle-aged workers. With the persistence of postwar unemployment, pressure for a shorter workweek and lowered retirement age have come to be recognized primarily as devices for spreading work, and only incidentally as a source of increased leisure.

When leisure appears as a byproduct of efforts to provide jobs to a larger number (or a different group) of workers, the utility of the added free time is called into question. It is not surprising, therefore, to find current writers debating whether the new leisure is a blessing or a curse. The popular press contains repeated references to the demoralization of teenagers who have no after-school farm chores to perform and to the plight of the retiree with time on his hands. The scholarly journals probe into such questions as the meaning of work for different individuals, the attitudes of different socioeconomic groups toward leisure time, and occupational variations in the patterns of leisure-time activities. Concern for a "meaningful use of leisure time" is often expressed, the implication being that the reduction in working time needs to be accompanied by some form of self-improvement, lest free time become synonymous with wasted time.

While technology gives the worker more time free of work, it also demands that he be more highly trained (or differently trained) while he is on the job. The need for improved labor force quality, prompting nationwide retraining and relocation programs, has led also to reappraisals of the Nation's educational levels and goals. Economists have analyzed the relation between investments in education and the rate of economic growth and have concluded that sometimes the investment in human capital pays a higher return than that made in physical capital. The diversion of free time into education thus has great appeal, both as a short-run "constructive" use of time and as a long-run source of return.

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[1] Paul F. Douglass, Foreword to "Recreation in the Age of Automation. *Annals of the American Academy of Political and Social Science*, vol. 313 (September 1957), p. ix.

In the subsequent review of some recent contributions to the study of leisure, several major areas of thought are treated: The extent of growth in leisure; estimates of the value of increases in nonworking time and the effect of adding this value to net national product; the allocation of leisure over different occupational groups, and in different forms; attitudes toward leisure; and the uses of leisure time.

1. The Growth of Leisure

The "leisure problem," Sebastian de Grazia argues, emerged with Europe's transition from an agricultural to an industrial era. The fight for a 10-hour workday in England, which was initiated not so much as a struggle for shorter hours as a tactic for spreading the work, later came to reflect a genuine wish for free time. Once a family had worked enough hours to finance its basic needs, time away from the factory, rather than a higher living standard, was preferred. This hangover of the country mentality, which men recently moved from the villages found difficult to lose, persisted until a new generation of workers appeared. The new group had their work habits formed under factory supervision while they were children, and in this formative process lost the drive for independent free-time activity. The discipline of factory life thereafter separated work and free time completely.

But free time is not to be confused with leisure; according to Mr. de Grazia, free time or time free from work has not increased as much as is commonly thought. Leisure, which he equates with contemplation, presupposes the existence of free time but accounts for only a small (and not necessarily growing) portion of the time man does not work. "There is no doubt that Americans have reached a new level of life. Whether it is a good life is another matter. This much is clear; it is a life without leisure."[2]

The American worker, the author concedes, has chalked up an additional 31 hours per week in time free from the job during roughly the past century. But this average is derived by including the hours worked by part-time workers. If the workweek under discussion is the number of hours worked by those persons who are full-time participants, the average is not 39 to 40, but 46 to 47 hours. After increases in vacation time are counted in, the full-time worker's gain has been about 25 hours, not 31. Taking into account travel time to and from work (about 8½ hours) and hours spent on do-it-yourself projects in or around the house (5 per week), the gain is further reduced to about 11 hours per week. This figure is again lowered by an allowance of 2.3 hours per week for time men spend on household chores, and the remaining 8.5 hours are probably not a clear gain in free time during the century. Heavy losses of time attend today's great mobility of workers and their families, the fatigue accompanying machine-pace work, women working, moonlighting, etc.

In contrast to Mr. de Grazia's conclusion that workers have gained, on a weekly average, only a few additional hours of free time during the past century, J. Frederic Dewhurst[3] estimates that the workweek fell from about 70 hours in 1850 to 44 hours in 1940. Joseph Zeisel reports a further drop to 41.5 hours by 1956.[4] Although rising productivity and higher real incomes would appear to lead to further increases in the demand for free time, Mr. Zeisel points out that the growth of dual job holding indicates, instead, a desire for income. Nevertheless, he concludes that the average number of hours worked per week and per year is likely to continue to fall. Technological advance will support this trend; increased labor force participation by teenage youth and married women will lead to a downward movement in hours, as will the growth in holidays, sick leave, and paid vacations.[5] In a more recent article Peter Henle notes that for the period 1940–60 there has been, on the average, an additional 155 hours of leisure time annually for the full-time employee. This free time has been divided approximately evenly between shorter hours per week and paid vacations and holidays.[6]

Various estimates have been made of the proportion of productivity increase being taken in the form of free time, as opposed to the amount taken in increased wages. William Haber estimates that in the past about 40 percent of the productivity gain has gone into leisure.[7] George Soule, who includes in his estimate of the increase in free time the hours resulting from (1) reduction in the workweek; (2) later age of entry to the labor force; (3) growth of paid vacations; (4) earlier retirement; and (5) reduction in amount of housework, concludes that the Nation now has 100 billion hours a year more in free time than it had in the early days of its industrial development. Moreover, if this gain in free time had been foregone and output increased, instead, the total volume of goods and services produced would be at least 50 percent above its present level.[8]

Although the amount of free time gained during the past century has frequently been estimated, there have been only occasional attempts to place a dollar value on this added leisure. In Simon Kuznets' calculation of the value of leisure added in the period 1869–1948, he assumes a maximum initial standard workweek of 78 hours, and shows the amount of leisure as the excess of this figure over the actual standard workweek. Thus, a workweek of 67 hours (in 1869–78) left a weekly leisure of 11 hours, whereas a workweek of 48 hours (in 1939–48) left 30 hours per week for leisure.[9]

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[2] Sebastian de Grazia, *op. cit.*, p. 327.

[3] J. Frederic Dewhurst and Associates, *op. cit.*

[4] Joseph S. Zeisel, "The Workweek in American Industry," *Monthly Labor Review*, 81 (January 1958), pp. 23–29.

[5] *Ibid.*, p. 28.

[6] Peter Henle, "The Quiet Revolution in Leisure Time," *op cit.*

[7] William Haber, "The Shorter Workweek Issue," *Addresses on Industrial Relations*—1957 series, Bull. 25, Ann Arbor, 1957.

[8] Soule, *op. cit.*, pp. 59–60.

The value of leisure is then computed in two ways. First, assuming that the labor part of the national product is attributable to the labor involved in the standard workweek, Mr. Kuznets calculates the hours of leisure as a percentage of the standard workweek, then multiplies this percentage by the share of national product labor receives as compensation. In 1929 prices, the value of leisure by this computation rose from $1.2 billion per year in 1869–98 (11 hours of leisure is 16 percent of the standard workweek of 67 hours; 16 percent of the proportion of net national product going to labor—a proportion of 0.8 percent—equals $1.2) to $54.0 billion per year in 1939–48, when 30 hours of leisure constituted 62 percent of the standard workweek of 48 hours.

In the second method of computing the value of leisure, nonworking time is taken as a percentage, not of the standard workweek but of all committed hours—hours that must be used to all ends except leisure in order for work to be carried on. Increased leisure, being a much smaller proportion of committed hours (all clock hours minus leisure) than of workhours, is found to be of significantly less value under this second assumption. The value increased from $0.5 billion per year in 1869–78 to $19.2 billion annually in 1939–48.

Mr. Kuznets believes the first assumption is more appropriate. The rate of growth of the value of leisure, he concludes, is quite high, reflecting both a high rate of growth in leisure hours and a high rate of increase in productivity. The flow of goods to consumers, not counting leisure, rose from $8 billion at the beginning to $100 billion at the end of the period—a twelvefold increase. When the value of leisure (as estimated by the first method) is added, the aggregate value rose from $9.3 billion to $154 billion, or fifteenfold. On a per capita basis, the comparison was as follows: From $185 to $728, or almost three times when leisure is omitted; from $213 to $1,119, or over four times, when leisure is included. The author concludes that

> . . . If we take into account not only the material goods and services provided by the economy to its ultimate consumers but also the amount of leisure which it leaves at their disposal, the rate of growth in the economic value of goods provided for satisfaction of consumers, on a per capita basis, does not slow down significantly.[10]

Mr. Kuznets' backward look at the leisure component of economic growth can be compared with Charles D. Stewart's projections of GNP to 1970, which afford an estimate of the effects of further reductions in working time. A 37-hour week (based on an annual man-hours model, rather than a scheduled 37-hour workweek), would yield a 1970 GNP of $676 billion at 1954 prices, and a gross national product per capita of $3,310. A 30-hour week would raise GNP to $567 billion, or $2,777 per capita, in 1954 prices. The choice of greater leisure can thus be weighed against the estimated value of goods which are foregone. Real income would rise (from a 1954 per capita gross national product of $2,220) in either case, the anticipated productivity increases more than offsetting the reduction in hours, even if hours were lowered to 30 per week.[11]

In appraising Mr. Stewart's models, Clark Kerr predicted a more modest reduction in hours of work than the three-per-decade average of the past century (which resulted partly from the shift of workers out of agriculture), and certainly a smaller reduction than the four-per-decade of the past half century. There could be wide variations in the worktime arrangements, as the number of hours is reduced, reflecting a diversity of preferences on the part of workers as to the form of leisure. By 1970, a 1,700 hours-per-year contract, instead of a 40-hour per week one, may be common. Increasingly, the worker's desire to work until the utility of the added income is more than offset by the disutility of the work, but no longer, may come to be felt in the work schedules. The more flexible the scheduling offered, the greater the number of persons joining the labor force from the peripheral of this increase, plus possible reductions in absenteeism and improvements in training and education, make the productivity consequences of reduced working time difficult to estimate.[12]

The assumption that total product would necessarily decline with reduced hours was questioned by Nelson N. Foote, who argued that leisure time, although unpaid, is not necessarily unproductive.

> The improvement of human resources and their utilization through hygiene, education, recreation, and the heightened exercise of imagination make a contribution to economic growth which is commonly underestimated . . . . Economists will soon have to commence evaluating the consequences of leisure from this standpoint.[13]

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[9] Simon Kuznets, "Income and Wealth of the United States," *op. cit.*, pp. 63–69.

[10] *Ibid.*, p. 67.

[11] Charles D. Stewart, "The Shortening Workweek as a Component of Economic Growth," *American Economic Review*, vol. 46 (1956), pp. 211–217.

[12] Clark Kerr, "Discussion," *American Economic Review*, vol. 46 (1956), pp. 218–223.

[13] Nelson N. Foote, "Discussion," *American Economic Review*, vol. 46 (1956), pp. 226–229.

Mr. Foote's conclusion that the volume of output in future years is dependent in part on current improvements in labor force quality, particularly through education, has subsequently been emphasized in the works of T. W. Schultz,[14] Gary Becker,[15] and others.[16]

2. The Distribution of Leisure

Discussions of the distribution of leisure have dealt with two major questions: One, how is the nonworking time apportioned over the different occupational groups within the labor force? And two, what form, or temporal distribution, does leisure take?

In the past two decades, as Mr. Henle noted above, the drop in annual working time of 155 hours per full-time worker has been divided almost equally between a reduction in workweek and an increase in vacations and holidays. Since 1960, the average workweek per full-time employee has shown little change, but the paid vacation time and holidays have continued to rise. The author suggests that by 1980 the workweek may still have fallen only slightly—1 or 2 hours—while paid vacations and holidays may have risen by 2 or 3 additional weeks.

Leisure viewed in the context of a lifetime has also increased significantly during the 20th century. Of the increase in life expectancy of approximately 18 years for men, about half has been added to the nonworking periods in youth and old age. The number of years outside the labor force has grown by 50 percent—from 16.1 years for a male born in 1900 to 25.2 for a male born in 1960. Although worklife expectancy also rose during the first half of the 20th century, it declined by half a year in the decade of the 1950's.[17] With the emphasis on early retirement during the 1960's, a substantial increase in the amount of leisure accruing in the form of retirement can be expected. Postponed entry to the labor force is also predicted, given the high unemployment rates for teenagers and the consequent pressure for extended education and training for youth.

The value of a given amount of leisure is to some extent dependent on the form in which it occurs. Although, as Clark Kerr has pointed out, workers' preferences vary, there is nevertheless evidence that full-time leisure in the form of retirement is frequently resisted, whereas additional vacation time is a highly desirable contractual provision. The temporal distribution of income, as well as that of leisure, is involved, obscuring the nature of the leisure preference. But without regard to the form of leisure, it is increasingly evident that the distribution of nonworking time among the workers of the labor force is extremely uneven, with the result that certain groups of workers have failed to share in this component of growth.

Harold T. Wilensky's analysis of the distribution of leisure shows a disproportionate gain in leisure in mining and manufacturing, and (since 1940) in agriculture. By contrast, civil servants and the self-employed have gained little or none. Certain groups of workers (white-collar workers—salesmen, clerks, proprietors, managers, officials, and most professionals) tend to work full time year round, while rural workers, women, nonwhite young and old workers are part-time or intermittent employees. Even the professional who takes a 4-week vacation is likely to work 2,400 hours (48 weeks at 50 hours per week) per year for 40 years, or 96,000 hours. The year-round, full-time blue-collar worker with 2 weeks of vacation works 2,000 hours (40 per week for 50 weeks) for 47 years, or 94,000 hours. But since the blue-collar worker seldom works full time for the entire year, his nonworking time far exceeds that of the professional.[18]

The author's conclusion that the upper strata have probably lost leisure during the 20th century is based upon several findings. Among a sample of lawyers, professors, engineers, and the middle mass (clerks, salesmen, craftsmen, foremen, small proprietors, semiprofessionals, technicians, managers, and some operatives, with incomes ranging from $5,000 to $13,000), about half worked 45 hours or more weekly, and a sizable minority worked 60 hours or more. Ten percent held spare-time jobs at the time they were questioned, and a third had been a moonlighter at some time in his worklife. One-third of the high-income men ($10,000 or over) logged 55 hours or more, as compared with one-fifth of those men who made $10,000 or less.

The differences in work schedules within strata are even more pronounced, however. One-fifth of all lawyers and one-fourth of the professors have workweeks of fewer than 45 hours; one-half the engineers and the middle mass have such short workweeks. Being self-employed, Jewish, or high income tends to raise the propensity for long hours. Small proprietors have the longest workweeks (50 percent work 55 hours or more) and solo lawyers are second. Men who control their work schedules (particularly those with incomes of $10,000 or more) work long hours more often than men on fixed schedules.[19] Another author's breakdown of the average hours of business executives shows a workweek of 50 hours—43 at the office plus 7 at home; these hours exclude business entertaining at home, travel time to work, and business travel.[20]

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[14] T. W. Schultz, "Investment in Human Capital," *American Economic Review*, vol. 51 (1961), pp. 1–17.

[15] Gary S. Becker, *Human Capital* (New York, 1964).

[16] See, for example, *Journal of Political Economy*, vol. 70, No. part 2 (1962), and Frederick Harbison and Charles A. Myers, *Education, Manpower, and Economic Growth* (New York, 1964).

[17] Seymour L. Wolfbein, *op. cit.*

[18] Harold L. Wilensky, "The Uneven Distribution of Leisure," *Social Problems*, vol. 9 (1961–62), pp. 32–56.

[19] *Ibid.*, pp. 39–43.

Mr. Wilensky concludes that man's quantitative gains in leisure have been exaggerated, and the quality of leisure, being more rigid and fragmented, is far from ideal. Persons with leisure today are of occupational and age groups that are either motivated and able to choose leisure over income, or are forced into leisure because of inadequate job opportunities. The former cut across class lines, including college-educated engineers and the upper working class; the latter are concentrated in low-income and low-status jobs where "leisure" takes the form of unemployment and involuntary retirement.

3. Attitudes Toward Leisure

Authors differ in their opinions as to the value of the leisure that is emerging with productivity growth. Strong views hold that the increase in free time is for the most part creating problems; workers are not coping successfully with idleness but are bored with longer periods of free time, particularly during retirement. The counterview finds that there is still far less free time than man would like. His orientation to work has been due to a need for income, rather than a love of work—in reality, work was never as central to the workingman's life as is commonly assumed.

As was noted earlier, Margaret Mead holds that Americans have in the past felt it necessary to earn their leisure before they enjoyed it. But more recently, she concludes, the home ritual is absorbing the time freed by technology; new values, more appropriate to today's affluence, are replacing older values that sprang from economic scarcity. In contrast, Robert M. MacIver argues that the growing freedom from work merely provides "a great emptiness" for all but the placid people, and the placid are diminishing in number. "The days of unremitting toil" are thus removed, but the change is not necessarily for the better.[21]

How the workers feel about "unremitting toil" or even toil during relatively short workweeks is revealing. Robert Dubin reports that for three out of every four industrial workers he studied, work and the workplace are not central life interests. Although the worker recognizes the primacy of work he does not have a sense of total commitment to it, nor does he view his work or working relationships as the major source of his enjoyment, happiness, or sense of worth. The author suggests that "the problem of creating an industrial civilization is essentially a problem of social invention and creativity in the nonwork aspects of life," [22] as an earlier conference had concluded.[23] These inventions are likely to come, not in connection with worklife, but within the framework of community life.

Our sense of responsibility for how other people spend their leisure time is characteristic of American life; "our bonanzas, our windfalls . . . have been interpreted by the most sensitive and responsible among us as problems," is David Riesman's view.[24] We are in fact proud of being such responsible members of society that we ourselves have no leisure. But the author argues that criticism of the work-oriented Puritans is probably overdone. The moral seriousness of puritanism has in fact helped to bring society to the position in which leisure can become a problem for a majority of the people.

The problems inherent in the acquisition and assimilation of leisure are comparable, the author continues, to problems that arise in other areas of social progress; "every social advance is ambivalent in its consequences." Being at the frontier of the development of leisure, there are of course conflicts in attitudes toward its use. Knowing very little about what leisure means to people—how much they read, for example, or how widespread is the interest in painting or chamber music—assumptions are made that may in fact considerably understate the Nation's capacity for activities which earlier work schedules have prohibited.

Currently there are a number of areas of pioneering in leisure: Music, painting, and literature; sociability and conversation; sports. While these fields are being developed for masses of people, anxieties as to the values of leisure and the merits of using it in particular ways are to be expected. But Mr. Riesman argues that only historical amnesia can blind one to the humanizing effects of reduced work (including the elimination of child labor) and increased time free of work.

4. Uses of Leisure

Some of the ways in which Americans use their growing volume of free time have been described by authors of the preceding articles on the growth and distribution of leisure, and in the discussion of attitudes toward leisure. Margaret Mead refers to the do-it-yourself movement and the home-related pattern of leisure.

> The gay companionship of a large family, making do with a small house, one car and two dogs, has a way of fending off boredom and apathy and the de-

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[20] A. Heckscher and Sebastian de Grazia, "Problems in Review: Executive Leisure," *Harvard Business Review*, 37 (1959).

[21] Robert M. MacIver, *The Pursuit of Happiness* (New York, 1955). Ch. 6 is reproduced in Eric Larrabee and Rolf Meyersohn, *Mass Leisure* (Glencoe, 1958), pp. 118–122.

[22] Robert Dubin, "Industrial Workers' Worlds," *Social Problems*, 3 (1956), pp. 131–142.

[23] Eugene A. Staley, ed., *Creating an Industrial Civilization* (New York, 1952).

[24] David Riesman, "Some Observations on Changes in Leisure Attitudes," *The Antioch Review*, 12 (1952–53), pp. 417–436.

> mand for expensive entertainment. The car, the television set, the pets are seen as contributory to the home. Service on innumerable boards and committees in the community is also part of making the community safe for children.[25]

The demands on free time made by the household—upkeep and repair of the house, shopping, helping with the children, family visiting, etc., were detailed also by Mr. de Grazia, who finds that the remaining time from which leisure could be taken is very small indeed.

Systematic studies of actual leisure time activities have been few. Some time ago (notably before the appearance of television), George A. Lundberg and his associates conducted a study of the uses of leisure time, using diary records kept by several thousand people in Westchester County, New York. These people spent an average of 7 hours a day in activities classified by the authors as the leisure variety. Ninety percent of this time was used for eating, visiting, reading, public entertainment, sports, radio, and motoring (listed in the order of the amount of time consumed). As the amount of their leisure increases, women spend larger proportions on visiting, reading, and club work, while men devote greater proportions of their time to visiting, reading, public entertainment, sports, and radio. Although different groups of people observed quite similar patterns in the types of activity, time spent on each, etc., the authors concluded that their qualitative differences were apparently great. Thus, although all classes spent a large proportion of their time reading, there was a wide range in the type of literature read.[26]

For the most part, data on leisure patterns have been gleaned from studies of expenditures on various forms of recreation. One study made in 1955 found that Americans were spending over $30 billion on leisure activities, which was 50 percent more than they spent for clothing or shelter. Even so, this was only about 12 percent of disposable consumer income in 1955, whereas the 1947 proportion had been 14 percent. Within this market, specific items (liquor and movies, for example) declined significantly. Leisure expenditures are made primarily by those families with $4,000 or more, which even in 1955 included over 45 percent of the families. Improvements in the lower incomes also affected the character of the leisure market; "the yacht splurge of the 1920's is replaced by the outboard boom of today." [27]

Recent figures on growth in specific leisure-time activities in the period 1947–63 reveal startlingly large increases in visits to national parks (almost 500 percent), oversea travel (almost 450 percent); large increases in outboard motor sales, motor vehicle travel, horseracing attendance, sales of golf equipment, bowling activities, visits to art and other museums, the number of amateur musicians and symphony orchestras, the publication of new books, the number of copies of paperbound books sold. Consumer expenditures on these activities have increased as a proportion of the disposable personal income, with the share devoted to TV, records, musical instruments, sporting goods, and books rising sharply while that for movies, magazines, and newspapers declined. Travel expenditures, particularly the portion spent for foreign travel, experienced a spectacular growth.[28] As might have been predicted, one of the fast growing recreational activities—bowling—is rapidly being automated.[29]

The following commentary on the growth of leisure, entitled "Can Marriage Survive the Ten-Hour Week?" is reprinted from *Punch:*

> "As your solicitors will have told you, Mr. and Mrs. Arkworthy, under the Marriage Preservation Act of 1984, legal aid for divorce proceedings can only be granted if reconciliation has been attempted by the Marriage Guidance Council."
>
> "S' right," said Mr. Arkworthy.
>
> "Reconciliation?" pierced Mrs. Arkworthy. "I'll see myself in a straitjacket first."
>
> "Now, now, madam, do let us think positively. I am the marriage guidance counsellor assigned to your case. Regard me, truly, as your friend. Tell me, what has caused this sad estrangement?"
>
> "Him," said Mrs. Arkworthy.
>
> "Her," said Mr. A.
>
> "It was just about bearable, Mr. Counsellor, till the Government brought in their rotten 10-hour maximum working week. Now he's forever hanging round the house and getting under my feet."
>
> "A working man's got a right to take his leisure within the four walls of his own mortgage."
>
> "I wouldn't mind if he did something, like he used to. But now he just sits there in the armchair, whistling under his breath and watching me. Sort of sedentary lurking. Gets on a woman's wick."
>
> "A man's entitled to rest after a hard week's labour."
>
> "Ten hours a week he works, seven to five of a Sunday, keeping the chromium on that computer clean, bright and slightly oiled, and spends the rest of the week haunting me."
>
> "She had her way, I'd spend my offdays underneath the arches."

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[25] Mead, *op. cit.*, p. 15.

[26] George A. Lundberg, Mirra Komarovsky, and Mary Alice McInerny, *Leisure: A Suburban Study* (New York, 1934), ch. IV.

[27] *Fortune*, 1955, ch. X; reprinted in Larrabee and Meyersohn, *op. cit.*, pp. 161–72.

[28] See *Survey of Current Business*, July 1964, and tabular summary presented in Henle, "The Quiet Revolution in Leisure Time," *op. cit.*

[29] Russell B. Flanders, "Automation in Bowling Creates New Job," *Occupational Outlook Quarterly*, 9 (1965), pp. 21–23.

"He's got this uncanny knack of always sitting down just where I want to sweep up."

"Had to go down the doctor, I did, with arthuritis of the kneejoints through continually lifting my legs up horizontal for her to vacuum under."

"And I'm on the vitamin pills for housewives' exhaustion. With him watching me like a sitdown foreman and making with the sarcasm whenever I take a rest. I just keep compulsively houseworking all day long."

"Always cracking on, she was, about working her fingers to the bone when I was out all week and couldn't visually check her output."

"And I'm all day over the hot stove. He gets hungrier sitting down than he ever did standing up. I've got athlete's foot running in and out of that kitchen with coffee and biscuits. And regular every morning before half-past eleven he starts on about when's lunch going to be ready."

"Makes a man peckish watching housework."

"I wouldn't mind, Mr. Counsellor, if he'd do something. Hundred times, I've asked him, why don't you do some gardening?"

"Gardening? I been over our 160 square feet of horticulture that many times I know every blade of grass by its Christian name. Do something, she says, and then forbids me carpentry."

"Carpentry! May Barry Bucknall rest in peace. All he can do is make shelves. And he's made 'em. Hundreds. Everywhere. There's not a spare bit of wall in our house you can lean against without a shelf nicking between your vertebrae."

"I could do more than shelves. I could drill and all."

"When he first came on this 10-hour week, and before the full torpor set in, he used to shuffle round with that electric drill searching for unpierced woodwork to bore holes in. Give me the creeps, he did, prowling about revving. People used to ask was the place built out of gruyere cheese or infested with giant woodworm from outer space."

"She ought never to have give my drill to the dustman."

"I had to. Before the house came down from electric death-watch. . . . Used to sneak out to the pub every chance he got. Now I'd have to put a gun to his head to drive him round there."

"Everybody down the boozer has told every one of their stories 55 times each. I'll go raving mad if that guv'nor tells me once again how he won the perishing war."

"I used to have a nice, social life myself with coffee mornings twice a week. But I can't do that with him sitting there all the time."

"I'm not stopping you."

"Oh, yes, you are. How can my friends enjoy talking about their horrible husbands with you eavesdropping for the enemy?"

"Eavesdropping! All shouting at once about kids and sex and how to spend money so's you can hear 'em in the next street."

"Ah! Sex," said the marriage counsellor eagerly. "Good. Any problems? Utterly confidential, I assure you. Does uninterrupted propinquity, as we say in the trade, lead to perpetual familiarity and inordinate demands?"

"You can say that again. Dozing around all day and conserving his energy, he can't hardly sleep a wink at nights. Nasty one-track mind in daylight, too. Have to lock the door, *and* bolt it, when I'm dusting the bedroom. Makes stud bulls look celibate, he does."

"A distressingly familiar problem of the 10-hour week, Mrs. Arkworthy. Satan and idle hands, you know. Only one thing for it. Mr. Arkworthy will have to go down to the Labour Exchange."

"But I've got a full-time 10-hour job already."

"I know. I want you to sign on for three more."

An alarm clock began ringing on the desk.

"Ah! That's it for this week," said the marriage counsellor, gathering up his papers and reaching for his hat. "I'll look forward to seeing you again next Wednesday, Mr. and Mrs. Arkworthy."

"But what about our legal aid?"

"Have to wait till then, I'm afraid, dear lady. The Marriage Guidance Council has just gone over to a nine-hour week." [30]

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[30] Patrick Ryan's article appeared in the June 2, 1965, issue, pp. 814–815. Reprinted by permission of *Punch*, London.

APPENDIX

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